THE
JOURNAL OF GEOLOGY

FEBRUARY–MARCH 1907

THE DEVONIAN SECTION OF ITHACA, N. Y.[1] PART II

THE DISCRIMINATION OF THE NUNDA-CHEMUNG BOUNDARY

HENRY SHALER WILLIAMS
Ithaca, N. Y.

[*Concluded from page 598*]

THE CHEMUNG GROUP OF HALL

The name Chemung group was originally proposed by James Hall in the *Third Annual Report* of the New York State Geological Survey (p. 324), published as "Assembly Document No. 275" in 1839. The formation was described and lithologically distinguished from the rocks of the immediately underlying formation by the following characteristics:

> The tops of the hills and high grounds in the towns of Erie, Veteran, and Catlin, display a group of rocks and fossils very distinct from those last described. The essential difference is the lithological characters of the sandstone of this group in the absence of argillaceous matter in most of the layers, these being merely a pure siliceous rock, harsh to the touch, and generally of a porous texture; while still a large proportion of the mass consists of compact shales and argillaceous sandstones of a softer texture than those below. The surface of the sandstones is rough, while those below are smooth and glossy, and being never rippled, prove that the rocks were deposited in a quiet sea. (P. 322.)

This definition gives a fair idea of the most conspicuous differences separating the higher from the lower rocks of these sections,

[1] Published by permission of the Director of the United States Geological Survey. Concluded from p. 598 of Vol. XIV, No. 7 (1906).

though it would be difficult to draw a sharp line at the horizon where the change takes place.

The shales of the Nunda and Chemung are similar, but the sandstones of the Nunda are smooth surfaced, often ripple marked, thin and tough in texture; while they are soft, rough surfaced, breaking up with vertical rather than splintery fracture ("blocky" as I have called them), in the Chemung and are often of a lighter color.

In Hall's original definition of the formation certain fossils are mentioned as charactersitic: "The principal ones are a species of *Delthyris* the shell on each side extending into a wing (*D. alata*?) a *Leptaena*, *Orthis*, and a species of *Avicula* or *Pterinea*," etc., but we find a fuller list given in the final report published in 1844. Still more important than this citation of fossils for the purpose of identifying the typical characteristics of the formation is the following statement:

> Between Elmira and Chemung they are seen at numerous points, but nowhere in the county [Chemung] so well as at the Chemung upper Narrows, about eleven miles below Elmira. Here the excavation for the road along the margin of the river has exposed more than 100 feet of rocks, containing abundance of the characteristic fossils, and in their greatest beauty and perfection. (P. 323.)

This quotation indicates where may be found the typical representation of the fauna and, since in later papers the author [James Hall] lessened his belief in the separateness of the faunas of the Ithaca and Chemung, this standard section is important as it enables us now to scrutinize it more closely than Hall did and to discover the paleontologic marks by which it may be distinguished from the fauna underlying it.

Adopting therefore this section at the upper Chemung Narrows as containing the typical Chemung fauna, as recognized at the time of the original recognition and naming of the Chemung group by James Hall, we may select from the fossils named as characteristic of the Chemung group in the final report (1843) those which are known to belong to the section of rocks exposed at Chemung Narrows (*Geol. of Fourth Dist., N. Y.*, pp. 262 ff.).

The species originally mentioned by Hall as coming from the rocks at Chemung and Cayuta Creek[1] (the latter has been found by

[1] Ch.=Chemung; Cy.=Cayuta Creek.

later investigations to represent the same portion of the section as that seen at the cliff at the Narrows above Chemung) are the following, viz.:

Calymene nupera (Fig. 116, p. 262, Ch.) = Phacops nupera.

Avicula pectenformis (Fig. 117, 1, 2, p. 262, Ch., Cy.) = Pterinea chemungensis (Con.).

Avicula spinigera (Fig. 117, 4, p. 262, Ch.) = Leptodesma spiningerum.

Strophomena bifurcata (Fig. 120–2, Ch.) = Orthothetes chemungensis.

Strophomena arctostriata (Fig. 120, 3, Ch.) = Orthothetes chemungensis.

Strophemena interstrialis (Fig. 120, 5, Ch.) = Dovillina mucronata (Con.).

Orthis carinata (Fig. 121, 1, Ch.) = Dalmanella carinata.

Orthis interlineata (Fig. 121, 3, 4, Ch., Cy.) = Dalmanella tioga (Hall).

Delthyris mesastrialis (Fig. 122, 1, 1*a*, Cy.) = Spirifer mesistrialis.

Delthyris disjuncta? H. (Fig. 122, 3, Ch.) = Spirifer disjunctus Sowerby.

Delthyris cuspidata H. (Fig. 123, 1, Ch., Cy.) = Sp. disjunctus Sow.

Delthyris acanthota H. (Fig. 123, 2, 2*a*, Ch., Cy.) = Sp. disjunctus Sow.

Delthyris acuminata H. (Fig 123, 5, 5*a*, Ch., Cy.) = Delthyris mesicostalis.

Atrypa dumosa (Fig. 124, 1, 1*a*, Ch., Cy.) = Atrypa spinosa (Hall).

Atrypa tribulis (Fig. 124, 3, Ch.) = Atrypa reticularis (Lin).

Cyathophyllum p. (Fig. 273, Ch.) = ?

Conrad[1] in 1842 described several species, the locality of which is sufficiently well certified to refer them to this fauna. The species are (all from Chemung Narrows):

Avicula spinigera (p. 237, Pl. 12, Fig. 3) = Leptodesma spinigerum (Con.).

Avicula protexa (p. 238, Pl. 12, Fig. 6) = Leptodesma protextum (Con.).

Avicula multilineata (p. 241, Pl. 13, Fig. 1) = Avicula multilineata (Con.).

Avicula chemungensis (p. 243) = Pterinea Chemungensis (Con.).

Cypricardites carinifera (p. 245, Pl. 13, Fig. 14) = Goniophora chemungensis.

Inoceramus chemungensis (p. 246, Pl. 13, Fig. 9) = Mytilarca chemungensis (Con.).

Nuculites chemungensis (p. 247, Pl. 13, Fig. 13) = Schizodus chemungensis (Con.).

Strophomena lachrymosa (p. 256, Pl. 14, Fig. 9) = Productella lachrymosa (Con.).

Strophomena lima (p. 256) P. lachrymosa var. lima (Con.).

Strophomena mucronata (p. 257, Pl. 14, Fig. 10) = Douvillina mucronata (Con.).

Strophomena chemungensis (p. 257, Pl. 14, Fig. 12) = Orthothetes chemungensis.

[1] "Observations on the Silurian and Devonian systems of the United States with Descriptions of New Organic Remains," *Jour. Acad. Nat. Sci.*, VIII (Jan. 18, 1842), pp. 228, etc.

Strophomena delthyris (p. 258, Pl. 14, Fig. 19) = (?) Leptostrophia perplana.
Delthyris chemungensis (p. 263) = Spirifer disjunctus.
Atrypa chemungensis (p. 265) = Atrypa reticularis.

In the Final Reports on Paleontology,[1] a large number of species were added to these lists, but for the purpose of determining the typical Chemung fauna and settling its lower boundary these species should furnish conclusive evidence. Those of the list which are restricted in range in this original section may fairly be regarded as diagnostic of the Chemung formation at its typical outcrop.

The two lists contain the following twenty species:

1. Phacops nupera (Hall).
2. Pterinea chemungensis (Hall).
3. Leptodesma spinigerum (Conrad).
4. L. protextum (Conrad).
5. Avicula multilineata (Conrad).
6. Goniophora chemungensis (Conrad)
7. Mytilarca chemungensis (Conrad).
8. Schizodus chemungensis (Conrad).
9. Orthothetes chemungensis (Hall).
10. Productella lachrymosa (Hall).
11. P. lachrymosa var. lima (Hall).
12. Stropheodonta (Douvillina) muconata (Vanuxem).
13. Leptostrophia (? perplana) delthyris (Conrad).
14. Dalmanella carinata (Hall).
15. Dalmanella tioga (Hall).
16. Spirifer disjunctus (Sowerby).
17. Spirifer mesistrialis (Hall).
18. Delthyris mesicostalis (Hall).
19. Atrypa spinosa (Hall).
20. Atrypa reticularis (Linn).

Of these species No. 1, *Phacops nupera*, is a variety of the common species *P. rana*, if not identical; but it was obtained from a loose block, as we are told in *Paleontology*, Vol. VII, p. 27, so that it is not certainly a part of the original Chemung fauna.

No. 5, *Avicula multilineata*, is not referred to in later literature, and for correlation purposes it is too rare to serve as a diagnostic species.

No. 8, *Schizodus chemungensis*, is reported as from "near Ithaca and Cortland,"[2] and as the rocks of these localities are now known to lie at a horizon lower than the rocks of Chemung Narrows, the species ceases to be diagnostic of the latter formation.

No. 9, *Orthothetes chemungensis*, as a species has a considerable range: it is quite variable in its Chemung expression, so that the name without restriction will not constitute it a diagnostic species of the Chemung.

[1] *Paleontology of New York*, Vols. IV, V, VI, VII, and VIII.
[2] *Paleontology of New York*, Vol. II, p. 454.

No. 13, called *Strophomena delthyris* by Conrad, is quite distinct from the form described by the same name under the name *Strophomena perplana* to which it has been referred by Hall. If it be a variety of *Str. perplana Conrad*, it is sufficiently distinct to receive a distinct varietal name, and then will appear as *Leptostrophia perplana delthyris* (Con.).

Hall did not recognize the species called by him *Strophomena nervosa*[1] as coming from the Chemung Narrows section; nor does he list it from that section in the final description of the variety.[2] It may therefore be discarded from a strictly diagnostic list.

No. 17, *Spirifer mesistrialis*, in the final description of the species is listed from near Cortlandville in Cortland County. The rocks there exposed are stratigraphically at a lower horizon than Chemung, so that the species will not serve to settle the question as to whether the Chemung fauna is or is not identical with that of the Ithaca member.

No. 18, *Delthyris mesicostalis* Hall. This species was described from a specimen from Angelica, N. Y., and was not reported by Hall from the Chemung Narrows section. The form which has later been identified as of this species, was originally described as *Delthyris acuminata* by Hall; this specific name was dropped because it had already been used by Conrad for a Spirifer. This latter form was recognized by Hall as coming from Ithaca, and Cayuta Creek.[3]

This form (referred to by Hall under the name *Delthyris acuminata*) is a common Chemung species; but the discovery of its intimate association with the Tropidoleptus fauna, its close affinity with Delthyris consobrinus (also a Hamilton species), and its occurrence in the Van Etten and White Church zones of Tropidoleptus entirely below the range of *Spirifer disjunctus*, the Dalmanellas, the Douvillinas, and *Pterinea chemungensis*, has led me to believe that it does not belong to the typical Chemung fauna, any more than do *Tropidoleptus carinatus* and *Rhipidomella vanuxemi*, both of which are abundant in some zones of the section at Chemung Narrows.

Independently, therefore, of the question as to whether there is

[1] *Final Rept. Fourth Dist.* (1843), p. 266, Fig. 1.

[2] *Paleontology*, etc., Vol. IV, 113, 114.

[3] *Report Fourth Dist. N. Y.* (1843), p. 271.

a distinction between the Ithaca and Chemung forms going under the name, this species cannot be regarded as strictly diagnostic of the typical Chemung fauna.

Nos. 19 and 20, *Atrypa spinosa* and *Atrypa reticularis*, are both recorded from lower horizons than the Chemung by Hall in the *Paleontology of New York*,[1] so that they too must be discarded from the list as not strictly diagnostic of the fauna.

DIAGNOSTIC SPECIES OF THE TYPICAL CHEMUNG FAUNA

Excluding the above mentioned species there are left the following eleven species characteristic of the original Chemung group, as expressed in the section at Chemung Narrows a few miles west of the town of Chemung, viz.: *Pterinea chemungensis*, *Leptodesma spinigerum*, *Leptodesma protextum*, *Goniophora chemungensis*, *Mytilarca chemungensis*, *Productella lachrymosa*, *P. lachrymosa lima*, *Stropheodonta* (*Douvillina*) *mucronata* (Van.), *Dalmanella carinata*, *Dalmanella tioga*, *Spirifer disjunctus*. The question may appropriately be raised what is the known vertical range of these species, and how sharply may the Nunda-Chemung boundary be drawn by means of their appearance in the rocks?

Range of the species.—The first species, *Pterinea chemungensis* (*Conrad*), is reported only from this Chemung locality and formation in the *Paleontology of New York*.[2] In that volume several closely allied species are described; in the case of none of the species is a locality or range indicated which would exclude them from this fauna. The species are *Pterinea consimilis* Hall, from Bucks quarry and Chemung, Chemung County, and Smithboro, Tioga County; *Pterinea rigida* Hall, from several localities in Chemung County; *Pterinea prora* Hall, from Bucks quarry and Chemung upper Narrows; also *Pterinea* (*Vertumnia*) *reversa* Hall, and *Pterinea* (*Vertumnia*) *avis* Hall; the subgenus Vertumnia was erected on the character of reversal of the characters of the opposite valves of the shell so that the right valve of Vertumnia appears like the left valve of typical Pterinea The species of Vertumnia are also restricted to the horizons through which the normal species range.

[1] *Op. cit.*, Vol. IV, 1867, pp. 321, 325.

[2] *Op. cit.*, Vol. V, 1884, p. 98.

In the sections examined in the Watkin's Glen quadrangle the range of all these species of Pterinea is restricted to the Cayuta member of the Chemung formation, as defined in this paper, except in a few doubtful cases where the species run higher up than the supposed termination of the Cayuta member into the Wellsburg.

Eastward, in the Harford quadrangle, the species *Pterinea chemungensis* has been discovered at a horizon below the range of the other species of the Chemung fauna. The fauna with which it is there associated is however sufficiently distinct from the typical Chemung fauna to leave little doubt as to a lower horizon. In one case Clarke has reported it at the extreme eastern edge of the Harford quadrangle in association with *Strophedonta cayuta*.[1] Neither of those species has been discovered in the Watkin's Glen quadrangle below the base of the Chemung formation. Clarke also records *Stropheodonta cayuta* in the West Hill sandstone of the Canandaigua and Naples quadrangles[2] and in the West Hill flags and shales of the Watkins and Elmira quadrangles.

While a failure to discover fossils is no evidence that they are wanting, it may be stated that none of the surveying party with the present writer examining the rocks of the Watkins Glen quadrangle has discovered either the *Pterinea* or the *Douvillina* below the stratigraphic base of the Chemung, thus making both of these species a fairly satisfactory evidence of a Chemung horizon for the Watkins Glen quadrangle, though it is not possible to say that they do not appear at a lower level within this province.

Leptodesma spinigerum and *Leptodesma protextum* are recorded from Chemung Narrows and both occur in the Chemung section there. They, however, vary so greatly in form and differ so slightly from the typical *Leptodesma Rogersi;* and there are so many species defined upon slight differences of form, that it will be difficult, without a more exhaustive study than has been given them to use species of this genus in defining the limits of the Chemung fauna. From the fact of the frequent abundance of species of this genus in the zones carrying such other species as *Tropidoleptus carinatus* and *Rhipidomela vanuxemi*, I am inclined to think that they belong to the

[1] *N. Y. State Mus. Bull.* 82, 1905, locality number 2499, pp. 53–70.

[2] *N. Y. State Mus. Bull.* 63, 1904, p. 64.

incursions of the Hamilton species into the region, rather than to the typical Chemung fauna. The Leptodesmas are not abundant in typical Chemung faunules although they are abundant in zones included in the Chemung formation.

Goniophora chemungensis (Van.).—In Hall's monograph on the Devonian Lamellibranchiata[1] this species is recorded from only the localities "Chemung Narrows and near Owego and Binghamton," all of which localities are estimated to be within the same stratigraphic limits, i. e., the Chemung.

In citing the above specific name, it should be noted that the original of the species named *Chemung cypricardite* (*C. chemungensis*) by Vanuxem[2] came from a locality "at the small bridge on the road to Lisle from Binghamton;" and the specimen coming from Chemung Narrows was described under the name *Cypricardites carinifera* by Conrad.[3]

Also, a closely related form was described by Conrad under the name *Cypricardites carinata* from "near Oneonta."[4] This latter specimen is figured on Plate II of the *Fifteenth Annual Report of the State Museum*.[5] Its close resemblance to the form figured by Vanuxem is evident. In fact Hall expressed his opinion that the original of Conrad's species *Cypricardites carinatus* is identical with Vanuxem's *Cypricardites chemungensis;*[6] but in his final monograph (above referred to), he recognized the two species as distinct. Thus in a critical case of identification, when stratigraphic horizon is in doubt, care should be taken to make clear the actual difference in form between the Hamilton form of the genus and the higher one coming from the Chemung. The horizon of the locality from which the original of Conrad's species *Goniophora carinata* came is in dispute. Its association with *Paracyclas lirata* does not prove it to belong to the Hamilton fauna, as pointed out by Prosser.[7] While the species

[1] *Paleontology of New York*, Vol. V, Pt. I, ii (1885), p. 303.

[2] *Rept. Third Dist. N. Y.* (1842), pp. 179, 181.

[3] *Jour. Acad. Nat. Sci.* (1842), Vol. VIII, p. 245.

[4] *Fifth Ann. Rept. N. Y. Geol. Surv.* (1841), p. 53.

[5] 1862, Pl. II, Fig. 21.

[6] Hall and Whitfield, *Preliminary Notice of the Lamellibranch Shells*, etc. (1869), p. 44.

[7] *Seventeenth Ann. Rept. State Geologist, N. Y.* (1900), p. 80.

described by Conrad as *Cypricardites carinifera* and that named and figured by Vanuxem as *Cypricardites chemungensis* undoubtedly occur at Chemung Narrows in the typical Chemung fauna, the characters by which they may be discriminated from other representatives of the same genus at horizons below the range of other typical Chemung species are too vaguely established to make certain that the species is confined to the Chemung formation. Closely related species of the genus do certainly occur below and probably above the Chemung formation.

Mytilarca chemungensis.—As a genus Mytilarca ranges throughout the Devonian and upward into the lower formations of the carboniferous and both the elongate form *M. chemungensis* and the shorter form *M. carinata* are frequently met with in the Chemung rocks. Several other species have been described from rocks of other than the typical section referred to the Chemung formation. The forms from the Ithaca and lower horizons most closely resembling the Chemung species are more gibbous, and upon this character and the more narrow form of the Chemung representatives of the genus they may be distinguished. So that this species and its closely related species may be used as strongly suggesting, if not strictly indicative, of a Chemung horizon.

One of the localities (2517) referred to by J. M. Clarke in the paper before mentioned as containing *Pterinea chemungensis* is also reported as holding *Mytilarca chemungensis*. Another significant species is *Leptostrophia nervosa*. The combination is one suggesting the Chemung fauna but the horizon is not clear. Clarke reports the locality as "Ithaca beds."[1]

Productella lachrymosa (Con.) and *P. lachrymosa var. lima* (Con.).—There is no doubt that forms of the genus Productella falling strictly under the description of Conrad's species *Strophomena lachrymosa* are present in the typical Chemung zone at Chemung Narrows as well as the variety *S. lima*. The question may be raised, however, whether this species is diagnostic of the Chemung fauna in New York state. Examination of a large number of faunules containing representatives of the genus demonstrate that the prominent characteristics of *P. lachrymosa*, i. e., the ventricose general form, large

[1] *N. Y. State Mus. Bull.*, 82, p. 60.

size for the genus and elongate tubercles scattered sparsely over the surface, become conspicuous at the horizon where the line between Nunda and Chemung is drawn. Nevertheless, specimens occur below this line which might be referred to the species, though they do not express the dominant characteristics of the species at these lower horizons. The dominant forms in the faunules below the line differ either in size, and thus become referable to the species *P. shumardiana* or *P. spinulicosta;* or else differ in the surface markings and fall under the definition of *P. speciosa* in which also the form is less ventricose and the initial umbonal portion is relatively sharper and narrower in relation to the full dimensions of the shell. The Chemung fauna is therefore characterized by the presence of *Productella lachrymosa* and its variety *P. lima*, but on account of the great plasticity of the genus, and the fact that the genus is abundantly represented in the Brachiopod faunules anywhere above the Genesee as at present defined, it cannot be said that the species as defined is strictly diagnostic of a Chemung fauna and horizon.

Stropheodonta (*Douvillina*) *mucronata* (Con.).—This species was originally described by Conrad under the name *Strophomena mucronata*, from Chemung Narrows, associated with *Productella lachrymosa*.[1] It was next referred to by Hall under the name *Strophomena interstrialis*. Hall regarded it at that time as identical with Phillips' species of that name.[2] Later Hall described the same species as a new species under the name *Stropheodonta cayuta*,[3] applying the name proposed by Conrad to the form occurring abundantly at Ithaca which had been already well figured by Vanuxem[4] under the name *Strophomena interstrialis*. Hall thus confused under the specific name *mucronata*, both species which he distinguished in the separation of the original figures in his report as 5 and 5*a* from 5*b* and 5*c*, referring the latter two, which present the typical character of Conrad's description to a new specific name *Stropheodonta cayuta*, and applying Conrad's name to the first two of the set which do not offer the distinctive characteristics of Conrad's description. The result,

[1] Conrad, *Jour. Acad. Nat. Sci.* (1842), p. 257, Pl. 14, Fig. 10.

[2] Hall, *Geol. Fourth Dist. N. Y.* (1843), p. 266, Fig. 5.

[3] Hall, *Paleography of New York*, Vol. V (1867), p. 110.

[4] Vanuxem, *Geol. N. Y. Rept. Fourth Dist.* (1842), p. 174.

which has come to light in noting the subgeneric differences indicated by the names Leptostrophia H. and C. and Douvillina Oehlert, is that the species characteristic of the Chemung fauna of New York, is the one originally described by Conrad from Chemung Narrows. This species belongs to the subgenus Douvillina and is properly therefore named *Stropheodonta (Douvillina) mucronata* (Con.).

All the faunules collected by the writer's party in the Watkin's Glen and Catatonk quadrangles which contain this species offer no evidence to contradict their reference to the Chemung fauna and Chemung formations as defined in this paper. No case has been discovered by them of the presence of the species at a horizon below the Chemung base. In the two quadrangles 183 faunules have been examined containing this species and of none of them is there any reasonable doubt (either structural or paleontological) as to their stratigraphic position above the Nunda-Chemung boundary as established in this classification.

A faunule from Marathon reservior, R. Ruedemann collector, No. 2499, is reported by J. M. Clarke as belonging to the "Ithaca beds."[1] Although the altitude is not given several of the species named do not indicate a horizon so low as the Ithaca. The species listed are:

Tentaculites sp. incert; Actinopteria eta. (Hall); *Pterinea chemungensis* (Con.); *Grammysia bisulcata* (Con.); *Microdon bellistriatus* (Con.); *Nucula varicosa* (Hall?); *Palaeoneilo emarginata* (Con.); *P. tenuistriata* (Hall); *P. sp. incert; Schizophoria impressa* (Hall); *Leptostrophia mucronata* (Con.); *Stropheodonta cayuta* (Hall); *Str. cf demissa* (Con.); *Chonetes scitula* (Hall); *Productella lachrymosa* (Con.); *P. sp. incert.; Spirifer mucronatus* (Con.); *S. mucronatus posterus* (H. and C.); *S. mesastrialis* (Hall); *S. laevis* (Hall); *Atrypa reticularis; Cyrtina hamiltonensis var. recta* (Hall); *Pugnax pugnus var. altus Calv.; Leiorhynchus globuliformis* (Van); *Strictopora gilberti; Hederella; Plumalina plumaria* (Hall); *Taxocrinus; Auloprora; Boring sponge; Lepidodendron; Dadoxylon.*

The species whose place in this list seem to the writer questionable are *Pterinea chemungensis, Stropheodonta cayuta,* and *Productella lachrymosa.* If these species are correctly identified and occur in association with the other species listed they are not in accord with the evidence gathered by our party at Marathon, and in fact throughout the whole of the Catatonk quadrangle.

[1] *N. Y. State Mus. Bull.* 82, pp. 59 ff.

Dalmanella carinata Hall is described as coming from the localities Painted-Post, Chemung, and Jasper[1] under the name *Orthis carinata*. But in the final description of the species[2] it is referred to Painted-Post alone. The statement is made that it "has not been obtained from any other locality,"[3] and we are told that in many of its characters this species assimilates with *Orthis tioga* and one of the localities from which *Orthis tioga* is cited is Chemung Narrows. Hence we may infer that the species selected as typical of the Chemung Narrows section is *Orthis tioga*, and although *O. carinata* has been discovered there, Hall evidently changed his opinion as to the Chemung Narrows form while the final report on Paleontology was being prepared.

Dalmanella tioga Hall.—This species was originally described and figured by Hall[4] under the name *Orthis interlineata* Sowerby. It was later described by him under the name *Orthis tioga*.[5] Still later it was placed by Hall and Clarke in the genus *Schizophoria* King.[6] And in the year 1905 the characters of the species were shown by Williams to be those of the genus *Dalmanella*, not Schizophoria.[7] It was pointed out by Williams that in Schizophoria the pedicel valve is resupinate, and, in the upper Devonian forms, presents a distinct sulcus along the center of that valve. The pedicel valve of Dalmanella on the other hand is distinctly elevated into a fold or narrow ridge, and in that genus the valve with the sulcus is the brachial valve, which is always convex in Schizophoria. There are other internal characters to separate the two genera, but the above external characters are sufficiently large and conspicuous to be detected in the field and furnish the evidence of the genus Dalmanella, by which presence of the Chemung fauna may be established for this province. The genus was prominent in the Ordovician and Silurian and appears conspicuously in the lower Helderberg. The only report of the genus

[1] *Geol. N. Y. Rep. Fourth Dist.* (1843), p. 267, Fig. 1.

[2] *Paleontology of New York*, Vol. IV (1867), p. 58, Pl. 8, Fig. 30–32.

[3] *Loc. cit.*, p. 59.

[4] *Geol. N. Y. Rept. Fourth Dist.* (1843), p. 268, Figs. 3, 4.

[5] *Paleontology of New York*, Vol. IV (1867), p. 59, Pl. VIII, Figs. 20–29.

[6] *Op. cit.*, Vol. VIII, Pt. 1, 1892, pp. 212, 226, Pl. VI, Figs. 17, 18.

[7] *U. S. Geol. Sur. Bull.* 244 (1905), p. 86.

from the Hamilton is the case of the minute species *Dalmanella lepidus* Hall, reported to have been found in only a single locality on the shore of Canandaigua Lake, Ontario County, N. Y., and in few individuals.[1] In the great number of faunules gathered and examined from the sections now under investigation and the neighboring regions of the Watkins Glen and Catatonk quadrangles not a trace of the genus Dalmanella has been seen below the Nunda-Chemung boundary line (i. e., not in the Nunda, Ithaca, Genesee, or Tully formations). In the Chemung rocks, however, the genus is represented by at least three species, and in some zones abundantly.

The species *Dalmanella tioga* is common and often met with in the Chemung rocks of this section from a horizon, 100 feet above the base upward for five hundred feet where it becomes less frequent.

In the first one hundred feet it is represented by the smaller species *Dalmanella leonensis*, which in some zones is abundant; but this species has not been recognized in this region above about one hundred feet from the base of the Chemung formation.

The genus has been observed in seven faunules from the Watkins fifteen-minute quadrangle. In all these cases the faunules present other indications of a horizon at the base of the Chemung and the line has in all cases been drawn to include the genus in the Chemung formation.

In the Elmira quadrangle the genus has been observed in fifty-one faunules, and in all of them the evidence, on other grounds, leaves no doubt as to the Chemung horizon of the strata containing them.

Twenty-nine faunules from the Ithaca quadrangle are equally clear as to the stratigraphic horizon to which the species of this genus belong.

From the Waverly quadrangle eighty faunules contain one or other species of the genus, and regarding none of them is there doubt as to the stratigraphic horizon to which they belong.

From the Dryden quadrangle fifteen faunules hold representatives of the genus.

In the Owego quadrangle the genus has been seen in seven faunules.

In the Apalachin quadrangle three cases have been recorded;

[1] *Paleontology of New York*, Vol. IV (1867), p. 46.

but no faunule has been discovered in the Harford quadrangle containing a species of Dalmanella.

Clarke cites no case of a Dalmanella in the list of species recorded from Central New York in the Ithaca fauna.[1] I have not observed in the various papers written by C. D. Prosser any report of a species of Dalmanella (or a species recorded under the name Orthis, now known to be Dalmanella) from the Devonian of Chenango Valley or further east in New York State, except the one case of *Orthis lenticularis* Van., from Chapman's Quarry, Babcock Hill, which is a typical Corniferous limestone.[2]

These facts indicate that eastward of the Ithaca meridian Dalmanella rapidly becomes rare and is rarely seen in Upper Devonian faunas beyond the Apalachin quadrangle eastward.

Tracing the evidence westward Clarke cites the species *Orthis infera* Calvin, which is a Dalmanella, from the fauna of the High point sandstone of Naples.[3] This species is small and closely related to *Orthis leonensis*. From the same fauna are cited also *Stropheodonta cayuta* and *Spirifer disjunctus*, thus leaving no doubt as to the Chemung character of the fauna.

In the Genesee Valley the genus is frequently met with in association with typical Chemung faunules.[4] In only one case in that bulletin is it reported from a doubtful horizon. This is the case of the shales at Hornellsville, Station No. 494. Here it occurs with *Cardiola* (*Buchiola*) *speciosa* and other species of the Nunda fauna. It is followed immediately by beds carrying *Spirifer disjunctus*. The species there is *Dalmanella leonensis*. This, with our present knowledge, locates the Hornell horizon in the *Dalmanella leonensis* zone at the base of the Cayuta member of the Chemung. A similar association takes place in the early faunules of the Watkins Glen and Elmira quadrangles, which indicates an over-lapping of the Nunda species upon the first incursion of the Chemung fauna. Still farther west in Chautauqua County the earlier Chemung faunas

[1] "Ithaca Fauna of Central New York," *N. Y. State Mus. Bull.* 82, pp. 53–70.

[2] "Devonian Section of Central New York," *N. Y. State Geol. Twelfth Ann. Rept.* (1894), p. 5.

[3] *N. Y. State Mus. Bull.* 63, p. 64.

[4] *U. S. Geol. Survey, Bull.* 41, pp. 30, 67, 69, 74, 76, 80, 85.

contain the smaller form of the genus called *Orthis (Dalmanella) leonensis*.

In the Chemung rocks of western New York the genus is almost as conspicuous as *Spirifer disjunctus* or *Orthothetes chemungensis*.

Taking in all the evidence the conclusion is drawn that Dalmanella is a characteristic genus throughout the whole Chemung in the western New York section; is more rarely present in the faunules of Genesee Valley; is conspicuous in the early and middle zones of the Chemung in the sections of Watkins Glen quadrangle; is rare in the Catatonk quadrangle, and is rarely ever seen further eastward.

The species *Orthis (Dalmanella) tioga* Hall,[1] was described from specimens derived near Factoryville in Tioga County, along Cayuta Creek, at Chemung Narrows, near Elmira, at Horseheads, and at Bucks quarry. It was also obtained from Allegany County at Phillipsburg, and near Leon and other places in Cattaraugus County, N. Y.

The species *Orthis (Dalmanella) leonensis* Hall,[2] is a smaller species and in the original description it is cited only from the Chemung group near Leon, Conewango and Randolph in Cattaraugus County, N. Y.

The Dalmanella leonensis zone.—Investigations into the range of the species of the genus in the Watkins Glen thirty-minute quadrangle show that the small form *Dalmanella leonensis* is confined to the lower one hundred feet (or a little over) of the Cayuta member of the Chemung formation. As it is often quite abundant in that zone the name *Dalmanella leonensis zone* is appropriately applied to it.

Common associated species of the faunule are: *Leptostrophia interstrialis; Productella spinulicosta; Spirifer disjunctus; Reticularia laevis; Palaeoneilo brevis; Pterinea chemungensis.*

Above the zone of *Dalmanella leonensis* the species *D. tioga* appears and in the sections along the meridian of Ithaca ranges upward through the Cayuta and Wellsburg members of the Chemung formation.

Spirifer disjunctus (Sowerby) may be regarded as a diagnostic species of the Chemung formation throughout New York state and its extension into Pennsylvania, Maryland, and Virginia. There are cases

[1] *Paleontology of New York*, Vol. IV (1867), p. 59.

[2] *Op. cit.*, Vol. IV (1867), p. 62.

of report of the species from rocks believed to be of a lower horizon than Chemung, but in several doubtful cases of this kind investigation has shown the absence of any conclusive evidence that the species was actually derived from the horizons mentioned.[1] In all cases in which the evidence is at hand for critical study no fauna containing authentic specimens of *Spirifer disjunctus* has been seen in New York or adjoining territory which upon any other kind of evidence can be satisfactorily thrown into a stratigraphic horizon below the base of the Chemung formation.

Many other species than those above mentioned have been listed from the Chemung formation, and they also may be recognized as good Chemung species; but it is important here to determine which particular species are diagnostic of the typical Chemung fauna, in order to establish an exact standard from which to trace the formation beyond the locality of its original definition.

In drawing the lines for the Watkins Glen quadrangle map the base of the Chemung formation has been discriminated by means of the above listed species. The formation line is thrown down as low as any of these diagnostic species have been certainly detected. This line has proven to be drawn consistently with the observed stratigraphy and conforms to the structural facts. This revision puts the line stratigraphically higher by some two hundred feet than I located it in 1884.[2] The faunule of Station No. 58 of that paper contains a species of Productella which I then identified with *P. lachrymosa*, and also the following species: *Ambocoelia umbonata* var. *gregaria*, *Orthis impressa*, and *Atrypa reticularis*. The faunas listed as 62*a* and 62*b* contain *Lingula complanata* and *Spirifer (Delthyris) mesicostalis*. All these are now thrown below the base of the Chemung, because of absence in them of the diagnostic species above cited.

The Van Etten Zone of Tropidoleptus.—The portion of the column thus thrown down from the Chemung into the upper part of the Nunda

[1] See Prosser, "The Devonian System of Eastern Pennsylvania and New York," *U. S. Geol. Survey, Bull.* 120 (1894), p. 12; Also Williams, "On the Formational Correlation of the Catawissa Section," in *Contributions to Devonian Paleontology, U. S. Geol. Survey, Bull.* 244, pp. 78 ff., 1905.

[2] "On the Fossil Faunas of the Upper Devonian," *U. S. Geol. Survey, Bull.* 3, p. 21.

upon paleontological evidence has been called the Van Etten zone of *Tropidoleptus*, for the expression of it seen in the rocks about Van Etten near drainage level. It was not known to contain *Tropidoleptus* in 1886, when I published the paper on the classification of the Upper Devonian.[1] Since then the fauna has been detected in several places. When well developed it contains the following species: *Tropidoleptus carinatus; Rhipidomella vanuxemi; Productella spinulicosta; Ambocœlia umbonata; Lingula complanata; Spirifer marcyi; Delthyris mesicostalis.*

Specimens of the latter species in external appearance are often very similar to the ordinary type of *Spirifer mucronatus* (= *pennatus*) of the Hamilton group.

Associated with these diagnostic species the fauna also contains species of the following genera, viz: Leiorhynchus, Leptodesma, Palaeoneilo, Grammysia, Modiomorpha (Cypricardella is not generally with it), Bellerophon, Coleolus, Pleurotomaria, Loxonema, Platyceras and occasionally Orbiculoidea, Chonetes and Camarotoechia.

One of the best places to see the fauna is in the ravine above White Church in the Dryden quadrangle, where it lies about two hundred feet below the base of the Chemung. On passing eastward the rocks of the upper part of the Nunda become more and more fossiliferous, and other species come in and probably other zones of the Tropidoleptus fauna; but in the Watkins Glen quadrangle this fossiliferous zone is frequently seen in the more eastern sections below the typical Chemung fauna, carrying several species which are common above, but never any of the species indicated above as diagnostic Chemung forms.

In the sections about Ithaca, traces of this same fauna are seen near the base of the Ithaca member in the zone I referred to in 1882[2] as a recurring Hamilton fauna. Since that paper was written the *Tropidoleptus carinatus* has been noted at the same horizon.

When these recurrences take place in the Watkins Glen quadrangle below the range of *Delthyris mesicostalis*, but above the Hamil-

[1] *Proc. A. A. A. Soc.*, Vol. XXXIV (1886), pp. 222 ff.

[2] "The Recurrence of Faunas in the Devonian Rocks of New York," *Proc. A. A. A. Soc.*, Vol. XXX (1882), p. 189.

ton, the horizon is (recognized as) in the Ithaca member of the Nunda; when the *Delthyris* is associated with them, but below the place of first appearance of the diagnostic Chemung species, the horizon is upper Nunda: i. e., the Van Etten zone of Tropidoleptus. Still later, after the Chemung species were upon the ground, in the lower part of the zone of *Dalmanella tioga*, Tropidoleptus again occurs. It is this third stage of its recurrence that was referred to in the list of species given on p. 24, of Bulletin No. 3 of the U. S. Geological Survey. It was numbered A^6+ and called "the second recurrence of the Tropidoleptus stage" in my paper on the classification of the Upper Devonian in 1886.[1]

The line thus determined as the horizontal boundary between the Nunda and the Chemung is traceable eastward as well as westward, by the range of the fossils which furnish a definite paleontologic means of discriminating the Chemung formation throughout its geographic extent.

The references to Dalmanella in *Contributions to Devonian Paleontology* of 1903[2] have been re-examined critically in the light of these investigations. All the citations of *Dalmanella tioga* and *D. carinata* are correct and the horizons containing them are unmistakably Chemung. The reference to the species *Dalmanella tenuilineata*, on p. 33 faunule 1379B, is based on a single specimen, and the species is the one described by Hall under the name *Orthis leonensis*.

The specimens identified, on pp. 36 and 37, as *Dalmanella tenuilineata* (from faunules $1380B^6$ and B^7) are in both cases associated with *Spirifer disjunctus* leaving no doubt as to the horizon, but they are specimens of a small Schizophoria and should not be referred to the genus Dalmanella. The specimen identified as Dalmanella in faunule $1453A^3$ on p. 70, does not exhibit the characteristic features of Dalmanella.

In using the faunal method of determining the boundary line between the Nunda and Chemung the assumption is made that a faunal distinction was applicable to the Chemung group as originally defined by Hall. This assumption is borne out by the later experience of paleontologists in finding distinct evidence of this fauna in

[1] *Proc. A. A. A. Soc.*, Vol. XXXIV (1885), p. 226.

[2] *U. S. Geol. Survey, Bull.* 244 (1905).

widely diverse regions of the United States. The attempt is made in the present discussion by close analysis of the fauna at the typical locality, to ascertain the particular species whose appearance in the strata begins at a definite horizon. This analysis has furnished the practical basis for drawing the line across the Watkins Glen quadrangle.

In order to explain the fact of such a definite change in the fauna at such a boundary line, it has been necessary to assume an incursion of the Chemung fauna from outside into the region at a particular point of time. Thereafter, for a considerable length of time, the species of fossils represented in the rocks were of the same fauna and constitute the typical Chemung fauna.

However, it must be distinctly remembered that such an assumption involves the pre-existence of the fauna in full vigor prior to the time of its incursion into this region.

If we were to assume that the species of the Chemung fauna were directly evolved from species living in the same region when the underlying rocks were being deposited, the sharpness of the line would necessarily be lost and no definite boundary horizon could be drawn on the basis of fossil faunules alone; for the reason that the change in specific character does not take place at such a rapid rate that the differences could be detected.

It is therefore considered to be a confirmation of the hypothesis of incursion of the fauna that the stratigraphic line marking the first appearance of the chief diagnostic species of the Chemung fauna occurs at a horizon so consistent with the general structure of the strata of a thirty-minute quadrangle. Another confirmation of the theory comes from the geographical extension of that horizon. On passing westward from the Ithaca meridian the line of separation of the faunas becomes more sharp and distinct; while on passing eastward the fauna below the line contains more and more species which are also found above the line.

In this eastern extension of the line, however the distinctive Chemung species become less dominant and as has been shown in earlier papers, the reappearance of species, which in the western New York outcrops are confined to horizons far below the boundary, is observed to be the rule rather than an occasional exception.

We are thus forced by the study of the facts, to the opinion that the horizon which is thus drawn on the basis of a change of the fossil faunas in the strata, while it represents at any one spot a definite point in geologic time, does not represent the same point of time in the sections of separate regions.

We are warned by the reappearance of many of the species of the Independence shale of Iowa in the fauna at the top of the Iowa Devonian series (Lime Creek shales), against the assumption that the same horizon is always indicated by the same fauna.[1] Correlation by faunas is always subject to the criticism that the mere presence of a fossil indicates only some point of time during the life history of that species. Nevertheless, in a restricted region, such as the one now under investigation, the first appearance in the stratigraphic column of a definite fauna, defines a definite geologic horizon with a high degree of precision. And so long as correlations are extended from the typical outcrop within the same geologic basin, the transition from one fauna to the next higher may be depended upon as marking the same point in the faunal histories whether they be considered as synchronous or only homotaxic.

[1] Calvin, *Iowa Geol. Surv.*, Vol. VIII, p. 222.

ABRASION BY GLACIERS, RIVERS, AND WAVES

LEWIS G. WESTGATE
Ohio Wesleyan University, Delaware, O.

INTRODUCTION

Erosion[1] or land sculpture includes rock disintegration, where the rock is coherent, and transportation of the material disintegrated. Disintegration has been divided into weathering and corrasion. Stream- and wave-wear may be either chemical or mechanical, though in all ordinary circumstances the mechanical wear is so much greater than chemical solution that the latter may be neglected. Ice-wear is purely mechanical. Omitting chemical solution, which is an entirely distinct process, corrasion may be defined as the mechanical wear performed by wind, streams, waves or glaciers. Gilbert[2] uses the term "corrasion," excluding chemical corrasion, for the "mechanical wear . . . . performed by the aid of hard mineral fragments which are carried along by the current." Chamberlin and Salisbury[3] define stream-corrasion as "the wear effected by running water." This use of the term is wider than that of Gilbert, for it includes not only wear by tools, but also the process of sweeping away material which has always been incoherent and "material loosened in advance by the process of weathering." To distinguish these radically different processes of stream-action, in this paper the term "abrasion" will be used for the mechanical wear performed by tools, and "plucking" for the removal of rock fragments. "Corrasion," including all mechanical wear by streams, will include both abrasion and plucking. None of the terms are new; they have more or less overlapped in use, and it is believed that the meaning here assigned to them is that generally understood today. The terms can be applied to glacier- and wave-action with the same significance with which they are

[1] Gilbert, *Geology of the Henry Mountains*, pp. 99–102.

[2] *Ibid.*, p. 101.

[3] Chamberlin and Salisbury, *Geology*, Vol. I, p. 113.

applied to stream-action. The analysis of erosion by waves, glaciers, and streams, would be arranged as follows:

Erosion { Rock-Disintegration { Weathering, Corrasion, Solution } { Abrasion, Plucking } ; Transportation }

In geological literature abrasion is ordinarily considered an important factor in land sculpture. It is the purpose of this article to suggest that abrasion by glaciers, streams, and waves is in most cases a negligible factor in erosion, and to emphasize the importance of weathering in the work of erosion by streams and waves. Wind-erosion is not considered.

GLACIAL ABRASION

The common understanding of glacial erosion has been that it is accomplished by the wear of solid particles held in the bottom of the ice against the rock surface over which the ice moved. This process would be favored by the weight of the glacier and by the fact that particles so held are often in continuous contact with the bed-rock for long distances. If this process were the only or the chief factor involved in glacial erosion, the rasplike action of the broad glacier bottom should produce a smoothed, sub-even surface. Within the glaciated area of North America there are many nearly level, glacially smoothed surfaces, but these are in regions which were level in preglacial times, and are areas which there is reason to believe were not deeply eroded. In the hilly regions of glaciated North America and in glaciated alpine valleys the detail of such surfaces is controlled by rock jointing, and glacial abrasion is limited to smoothing the surfaces and rounding the corners of the joint blocks. This hackly character of the topographic detail of surfaces covered by the Pleistocene ice-sheet may be in part an inheritance from pre-Pleistocene time, but in glaciated alpine valleys (see Fig. 1), having lateral hanging valleys, the rounded-hackly surface of the lower part of the main valley has been produced by the normal action of glacial erosion in live rock, scores and perhaps hundreds of feet below the original surface. Here plucking, or the removal of large blocks bounded by joint planes, has been the important element in erosion.

Before glacial abrasion has been able to smooth away the inequalities produced by plucking, the process of plucking has produced new inequalities. The effect of abrasion in wearing down the valleys is neutralized by the removal of the joint blocks when only partly abraded. It has been a pluck-and-heal process, with plucking always ahead. It is not a question here whether the blocks plucked are removed mechanically by the ice, or are loosened by subglacial weathering; the point emphasized is that valley-deepening does not take place through scratching by material carried in the bottom of the ice.

FIG. 1.—Joint-controlled glacially eroded surface. Direction of ice-movement was to left. The view shows the inability of abrasion to obliterate the control, by jointing and plucking, of the surface form. Lake Creek, above Twin Lakes, Colo.

There is nothing new in this statement of the process of glacial erosion. Plucking is recognized more and more. The relative incompetency of glacial abrasion is mentioned here because it leads up to the consideration of the inadequacy of stream-abrasion. The same class of facts is appealed to for evidence in both cases, and these facts have been recognized much more widely in the case of glacial erosion than in that of stream erosion.

STREAM-ABRASION

Stream-abrasion has generally been considered an important element in valley-cutting. It was clearly distinguished by Gilbert[1] and recent texts usually consider it, though no attempt has ordinarily been made to indicate the relative importance of abrasion, plucking,

[1] Gilbert, *Geology of the Henry Mountains*, p. 101.

and weathering. Chamberlin and Salisbury[1] go as far as any recent text in emphasizing the importance of weathering and plucking, and so in limiting the relative importance of abrasion in valley-cutting. They say that in any valley cross-section the amount removed by corrasion may be measured by a rectangle the width of which is the width of the stream, and the height of which is the depth of the valley. It seems, however, that even this relatively small proportionate amount, while allowed to the stream, must be denied to stream-abrasion, and divided between plucking and weathering.

Theoretically stream-abrasion is less probable than abrasion by glaciers. The cutting particles are not held against the rock bottom by any overlying mass of ice; indeed, the weight of the particles is lessened by their immersion in water. The smaller particles are largely carried in suspension, striking the bottom only at intervals. Fragments too large for suspension move over the bottom with rolling and not with sliding friction.

The form usually shown by the rock-bed over which the stream flows bears evidence to the inadequacy of mechanical wear of detritus in shaping it and in lowering the bed. The Olentangy River below Delaware, O., for example, is flowing over nearly horizontal beds of Devonian limestone. The bed of the river, which has since glacial time been cut a dozen feet into the hard rock, consists of a succession of very broad, low steps, each step being a limestone stratum, its down-stream limit determined by vertical joint-faces. In some places the edges, and in a few places the surfaces, of these steps are slightly rounded, as if by mechanical wear; but this in no way affects the large fact that the rock in the stream-bed is bounded by stratification- and torsion-joint planes. The agency effective in removing the rock from the stream-bed has taken it away in large blocks; the rock has not been scratched away by the mechanical rubbing of fragments swept down by the stream. The ordinary processes of weathering are believed to have loosened the jointed limestone, and the blocks were later swept away by the stream. As in the case of glacial erosion, before abrasion could reduce a joint-block, weathering processes isolated the partly worn block, and delivered it to the

[1] Chamberlin and Salisbury, *Geology*, Vol. I, p. 108.

stream for removal. In each case the character of the bottom bears evidence to the ineffectiveness of abrasion.

This fact in regard to the form of the stream-bed has been noticed by the writer in the streams cutting the Ohio shale and Cincinnati limestone (see Fig. 2) in Ohio, in the sandy shales near Ithaca, in the Berea sandstone of Ohio, in the Triassic sandstone along the lower Westfield River and the Connecticut River, and in the crystalline rocks along the upper Westfield River. Views showing stream-beds, notably the collection in Tarr's *New Physical Geography*, give evidence in the same direction.

FIG. 2.—Stream in thin-bedded Cincinnati limestone, in which the characteristic irregular surface of the stream-bed, the result of plucking rather than abrasion, is shown. Near Camden, O.

In qualification of what has just been said in reference to stream-abrasion, two things may be mentioned. First, reference should be made to pothole action. It is abrasion, and where numerous potholes are forming and connect, they may decidedly aid downward erosion. This action, however, is believed to be exceptional; the great majority of streams are without it. Secondly, and forming a really important exception, in certain cases streams are flowing over rock-beds which are thoroughly smoothed, and appear to have been deepened by wear of stream-swept detritus. In these cases it is believed that it will be found that the rock is nearly jointless. This is especially the case with crystalline rocks, particularly the more massive granites. This process of wear by abrasion is most common in swift streams in mountainous areas, but even here it is exceptional, and in the consideration of stream-erosion generally it is insignificant.

In conclusion, the joint-controlled form of the rock sides and

bottoms of stream-beds shows that abrasion has not been a determining element in valley-deepening, and that the stream is a transporting and not an abrading agent, removing materials dislodged from its bed or swept into it from its valley sides.

WAVE-EROSION

As in river-erosion, so in wave-erosion, abrasion, or the wear by material thrown against the base of the cliff, has been generally emphasized in the texts. Chamberlin and Salisbury[1] make corrasion by the impact of detritus an important element in wave-erosion on hard rocks, at the same time emphasizing the co-operation of weathering along joint planes. Geikie[2] says: "The waves make use of loose detritus within their reach to break down cliffs exposed to their fury. Probably by far the largest amount of erosion is thus accomplished." Le Conte[3] says that "fragments hurled against the shore are the principal agent of wave-erosion." But if abrasion has been the determining factor in wave-cutting, the shore in the vertical zone of breakers should bear evidence of this by its rounded and worn character. The only chance which the writer had to study rock shores with this consideration in mind was at Newport. In the hard conglomerate and sandstone at Easton's Point (see Fig. 3), on the south side of the island, no evidence of abrasion was found. To be sure, in some protected pockets, into which gravel had been swept

FIG. 3.—Shore on the east side of Easton's Point, Newport, R. I.

[1] Chamberlin and Salisbury, *Geology*, Vol. I, pp. 327–29.

[2] Geikie, *Text-Book of Geology*, Vol. I, p. 569.

[3] Le Conte, *Elements of Geology*, 5th ed., p. 34.

by the waves, the roll of the gravel had smoothed the solid rock; but elsewhere the waves are breaking either on surfaces which have not been appreciably eroded, or on a rocky shore composed of angular masses of rock of all sizes, which have been loosened by weathering. Wherever the shore is being worn, it is by combined weathering and plucking, and not by abrasion. Easton's Point is not yet marked by a wave-cut cliff, and so is not the best place to show the process of erosion; but along the Cliff Walk, at the west end of Easton's Beach, where the rock is prevailingly Carboniferous schists, a distinct cliff faces the ocean; the base of the cliff, however, is not rounded and smoothed as would be the case were it being worn back by abrasion. A very suggestive photograph of a raised wave-cut bench on Prudence Island has been published,[1] in which both cliff and bench are rough and angular, the detail determined by the jointing of the shales.

It will be easy, of course, for anyone to test the matter for himself. Detritus protects rather than endangers the cliff. Except at times of high storm, the beach material protects the cliff and acts on itself. It does not seem probable that the bombardment of the cliff at times of heavy storm would seriously affect the cliff. Certainly there is little evidence of such action in the detail of the cliff base. Waves acting by hydrostatic pressure along joint planes may be effective; apart from that action their work would appear to consist in reducing and removing materials supplied them by the processes of weathering. They, like streams, are transporting and not abrading agents.

RELATIVE IMPORTANCE OF PLUCKING AND WEATHERING

The mechanical work of corrasion has been divided between abrasion and plucking. Abrasion does not appear to be an important factor. It is further a delicate question as to how far plucking can be considered a separate process, to be distinguished from weathering on the one hand and transportation on the other. In the case of glacial erosion it is easy to believe that the pressure of the ice may dislodge blocks from a jointed floor which has not been affected by weathering, though it would be difficult to show that frost-weathering had not had a share in loosening these blocks. It is possible that a

[1] *Geology of the Narragansett Basin*, Monograph 33, U. S. Geological Survey, Plate XXIII.

similar effect may be produced on the sea-cliff in time of heavy storms. But the impact of storm-waves even would seem to be less effective than the pressure of glacial ice, and the fact that the cliff base is exposed to the air, and is often, and in some cases always, water-soaked, indicates that the loosening of the rock fragments which are finally dislodged by the waves is in reality the result of weathering. In the case of streams flowing over jointed coherent rock, it is difficult to believe that even the swift currents of flood seasons are able to dislodge rocks from the stream-beds. The impact of the water is too slight, and is exerted on the nearly flat stream-bed at a great disadvantage. The stream is able to sweep away blocks, not too large, which have been loosened and partly dislodged by weathering; but it is not easy to believe that the stream is the dislodging agent.

If, as seems certain in the case of stream-erosion,and as seems probable in case of wave-erosion, the loosening of the rock fragments is the result of weathering, then plucking becomes merely the first step in the transportation of débris, and is reduced to a vanishing quantity between weathering and transportation. In that case the stream becomes a transporting and not a corrading agent; weathering becomes the important factor in valley-deepening as in valley-widening; while the stream acting as a transporting agent prevents the process from clogging. To the extent that weathering replaces plucking by wave-action, the same thing is true of shore erosion. In glacial erosion only is plucking left as a large factor, and even here it is not certain that it is the only factor in joint-block removal.

THE SKULL OF PALEORHINUS

A WYOMING PHYTOSAUR

J. H. LEES
The University of Chicago

The University of Chicago paleontological expedition to Wyoming during the summer of 1904, under the direction of Dr. S. W. Williston, secured several phytosaurian skulls in excellent preservation. These skulls together with other fossil remains were collected from the Popo Agie beds of the Upper Trias of the Wind River region. One of these, made the type of a new genus by Dr. Williston and given its specific name in honor of its finder, Dr. E. B. Branson, has been studied by the writer during the past winter and the results of the work are here published. A preliminary announcement of the characters of this specimen, together with notes regarding the other specimens found at the same time, was issued some time ago by Dr. Williston (this JOURNAL, Vol. XII, 1904, p. 696).

General characters.—Skull greatly elongated, triangular; snout long, slender, depressed. External nares elevated, situated at posterior extremity of snout, entirely in front of antorbital vacuities, separated by downward extensions of nasals. Antorbital vacuities large; supratemporal vacuities small, completely enclosed; otic foramina present and completely enclosed. Quadrate foramina present, small. Squamosal extending but slightly beyond posterior margin of quadrate. Median notch of skull nearly in shape of isosceles triangle; notch above quadrate moderately deep. Plane of orbits directed obliquely upward.

Internal nares situated posterior to external, separated by vomers. Palatines separated by pterygoids. Vomers long and slender, separating pterygoids throughout, extending back to presphenoidal opening. Pterygoids long, entering into posterior margin of nares between palatines and vomers, extending postero-laterally in broad vertical plates for union with quadrates. Basipterygoid processes moderate in size, enlarged distally.

Posterior palatine foramina small, wholly enclosed by palatines and transverses. Presphenoidal opening small, cordiform. Teeth thirty-six on each side of upper jaw, two foremost larger and much elongated.

Mandible presenting high surangular crest and short posterior extension. Inner face bearing a strong, subrectangular process which springs from posterior extremity and extends anteriorly parallel to the ramus. Jaw rather slender, pierced by external and internal fenestræ and by small internal mandibular foramen.

Ilium bearing on outer face three strong ridges meeting in a high central knob above acetabulum. Posterior extremity continued in long process. Inner surface quite smooth except for long shallow trench for reception of sacrum, and two ill-defined ridges which bound it.

The skull is quite broad in the occipital region and narrows gradually to the region of the nares. A short distance in front of these the roof slopes downward and merges into the snout, which comprises about one-half the length of the entire skull. The snout is depressed and in cross-section its width is greater than its height. At the anterior extremity it is enlarged and somewhat deflected downward, and bears two large teeth on each side.

Viewed from the side the skull appears rather depressed, as its elevation is about one-half its greatest width. It presents a fairly even crest-line from its posterior margin to a position somewhat in front of the middle of the antorbital vacuities, where it begins to rise to the elevation upon which the nares open. From the nares the slope downward to the snout is rapid.

In the side view nearly all the external openings of the skull are visible—the anterior, excavated portion of the nares, the antorbital vacuity, the orbit itself, the lateral temporal vacuity, the quadrate foramen, and the opening of the otic capsule together with the small notch immediately beneath it. Only the supra-temporal vacuity and the deep median notch remain concealed. The skull is thus given quite a light, open appearance and has a much less massive aspect than some of the related belodonts, especially *B. kapffi*—or *Phytosaurus kapffi*, to follow McGregor—although this contrast is rendered more forcible by the slender snout of the specimen in

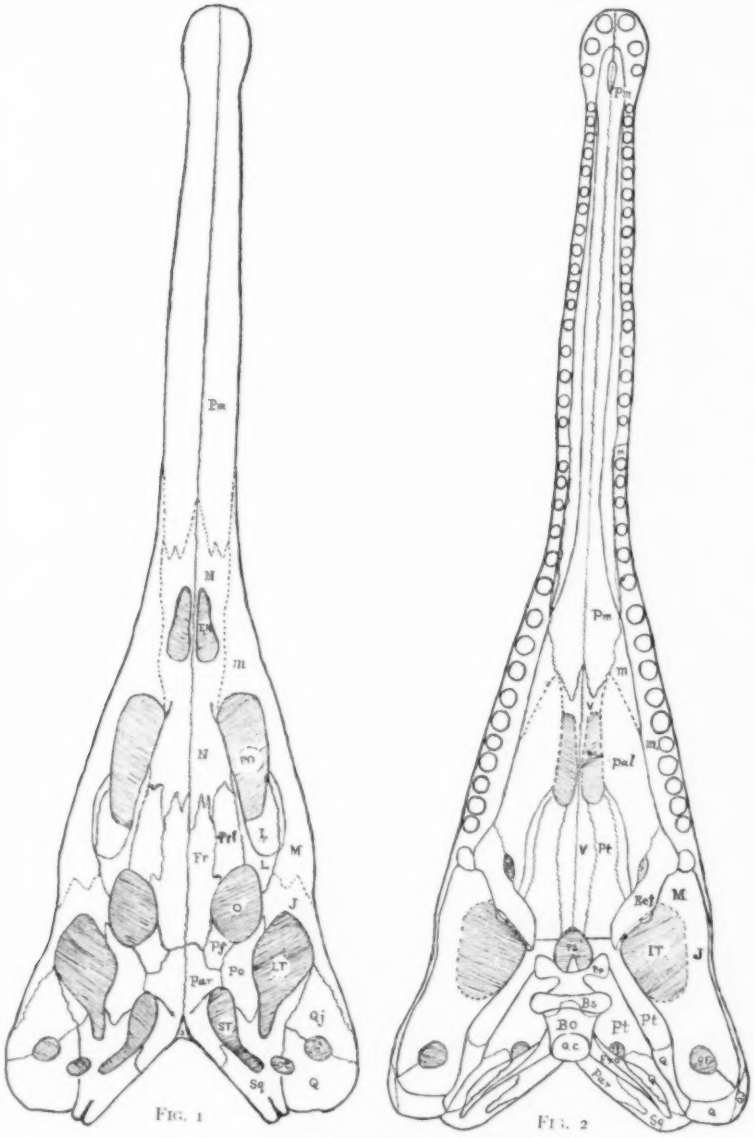

FIG. 1 FIG. 2

Skull of *Paleorhinus bransoni* Williston.

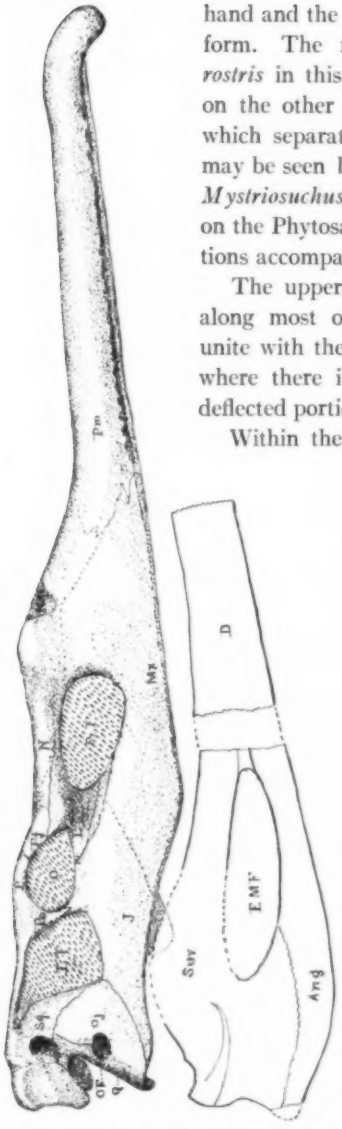

FIG. 3.—Skull of *Paleorhinus bransoni*, from the side.

hand and the enlargement of that in the European form. The resemblance to *Mystriosuchus planirostris* in this respect is much closer, but there are on the other hand some very marked divergences which separate the two individuals rather widely, as may be seen by a comparison of the illustrations of *Mystriosuchus* as given by McGregor in his paper on the Phytosauria. See bibliography and illustrations accompanying this paper.

The upper line of the snout is almost straight along most of its length, except where it rises to unite with the skull and also in the anterior region where there is a slight convexity just behind the deflected portion.

Within the line of the dental alveoli is a strong rounded ridge which probably meets a corresponding ridge on the mandible, as is stated by McGregor to be the case in *Mystriosuchus*, and thus prevented too forcible meeting of the teeth. These latter must have pointed obliquely outward.

The lateral bones of the skull are slightly roughened by irregular pittings and rugosities. This feature becomes more marked on the bones of the roof, especially on the frontals, where, between the anterior portions of the orbits, is a small area of very notable rugosity. Just anterior to this area the frontals are sculptured by narrow longitudinal ridges and furrows about one-eighth inch in width and one-half as deep, and with lengths up to one inch or more. The region between the antorbital vacuities is again roughened by small irregular tubercles and the

narial region is marked by small irregular pits and elevations, while the snout is rather smooth, with ornamentation about like that of the lateral portions of the skull.

Premaxilla.—The premaxilla is greatly elongated and makes up the entire rostrum except that portion immediately surrounding the nares. This part of the skull is, however, so shattered that the sutural relations of premaxilla, maxilla, and nasal cannot be determined with accuracy. Judging from von Meyer's figures of *Belodon* the premaxilla should extend to within about two inches of the nares, while the maxilla extends forward about two inches under the premaxilla. The indications point to this being the case. If this is true it gives the premaxilla a length of about fourteen and one-half inches.

The two premaxillæ were never fused; the suture remained distinct throughout life, and the union of the bones was so slight that the post-mortem crushing of the skull has caused them to slip over one another for almost one-half inch in one place.

Maxilla.—There seems to be a suture extending from a little in front of the middle of the upper border of the preorbital vacuity forward and slightly upward till it reaches a point opposite the middle of the naris, whence it descends rapidly, about parallel with the upper line of the snout, until it reaches the margin of the jaw about six inches in front of the point of its origin. This would be the union between the maxilla and the nasal for about four inches and between the maxilla and premaxilla for the anterior two inches. How far the maxilla extends backward and where it unites with the jugal cannot be positively stated, though by analogy with the European forms the union should be on that part of the cheek between the antorbital and lateral temporal vacuities. The maxilla lies below the lachrymal behind the antorbital opening and is united with that element for about two inches. Here it probably meets the jugal—about under the middle of the orbit. This would give to the bone a length of between eleven and twelve inches.

Nasals.—The nasals are also quite large bones. They extend from the premaxillæ backward about four inches posterior to the nares, which they entirely surround and which they separate by means of thin vertical septa, which pass downward for some distance in the median plane, how far is not determined, but since one

is exposed by the breaking away of the outer bony cover for at least one and one-fourth inches they must extend somewhat further beyond.

As is the case with the premaxillæ, and indeed with all the bones of the roof of the skull adjoining the median line, the median suture remains distinct. The nasal septa are plainly separate and the suture may be readily distinguished along the whole length of the skull as far as the supraoccipital where it becomes indistinguishable.

The nasal has not a very wide lateral extent, but if the boundaries as indicated in describing the maxilla are correct, it is limited to the upper part of the skull and has nowhere a width of more than one and one-half inches, although its extreme length is probably about nine inches. It is somewhat elevated around the naris, and so raises this opening slightly, and it is excavated for nearly its entire depth opposite the anterior half of the naris, leaving this open to the side for a depth of fully one inch. In life this lateral space was doubtless covered by the integument, confining the nostril to the upper surface of the skull. Whether or not the nasal reaches the antorbital vacuity is not certainly known, but it very probably does so for a short distance, perhaps from one-half to one inch, between the lachrymal and the maxilla.

Frontal.—Behind the nasal on the roof of the skull is the frontal, a long, narrow, subrectangular bone nearly four inches in length which unites with the nasal by a strong, splintery suture. The bone extends as far as the posterior limit of the orbit, a part of whose superior margin it forms. It is ornamented with irregular, longitudinal grooves and ridges on its anterior portion and by shorter pits and rugosities in the central and posterior regions.

Prefrontal.—This is also long and narrow, but is less regular in outline than the frontal. It is limited behind by the orbit and extends forward slightly beyond the frontal, where it terminates bluntly and is inserted into a notch in the nasal.

Lachrymal.—Between the prefrontal and the maxilla lies the lachrymal, a broad, irregularly shaped bone which forms the upper part of the arch between the orbit and the antorbital vacuity. Both of these openings penetrate this bone somewhat from front and rear, so that on the line between them it is constricted to a relatively narrow isthmus. The main body of the lachrymal gives off a slender anterior

process which forms the posterior half of the upper margin of the antorbital vacuity and excludes the prefrontal from this opening.

The lachrymal enters into and forms the greater part of a depressed area which lies behind the antorbital vacuity and extends almost to the orbit, leaving only a narrow bar elevated to form the lower anterior margin of the orbit.

Parietals.—Behind the frontals the parietals form the posterior portion of the cranial roof. They unite with the frontals by transverse sutures and are here narrow, but after widening gradually for about five-eighths of an inch they suddenly broaden to twice their anterior width and so continue, until they reach the anterior extremities of the supratemporal fossæ. They form the anterior one-half of the inner boundaries of these fossæ and here meet the squamosals in sutures which slant backward for some distance and then pass transversely to the edges of the median notch, along which they slope posteriorly so that on the under surface the parietals extend backward as thin narrow plates under the squamosals to within one-half inch of the posterior margins of these bones. That part of the parietal which borders the supratemporal fossa on its inner margin is deflected steeply downward and outward, leaving a long, oblique depression of triangular cross-section, in the outer wall of which the fossa is excavated. At a point a little more than one-half the distance from their anterior to their posterior margins the parietals separate and diverge widely, leaving a broad, rather deep, triangular recess which is bounded behind the parietals by the squamosals. This notch opens very gradually during the first one-half inch of its length, and then widens much more rapidly to the posterior margin of the skull. It is floored in its anterior part by the supraoccipital, and here the parietals nearly completely arch it over from side to side.

Jugal.—Behind the lachrymal and the maxilla lies the very irregularly shaped jugal. Its suture with the quadratojugal is exposed as a long curved line sloping diagonally backward and downward from the lower posterior angle of the lateral temporal vacuity almost to the point of the jaw. The posterior part of this element thus appears as a long, slender, wing-shaped extension forming the margin of the jaw. Anteriorly the bone widens, forms the cheek between the lateral temporal fossa and the margin of the skull and curves upward

in front of the fossa to form part of its anterior margin. This wing of the jugal tapers upward until at its union with the postorbital, which passes down to complete the margin of the fossa, it forms with the postorbital a narrow bar of about one-fourth inch width separating the fossa and the orbit. The jugal also forms part of the lower boundary of the orbit and here unites with the lachrymal. Its anterior limit and its union with the maxilla cannot be determined; the probable relations have already been discussed in connection with the maxilla.

Postfrontal.—The postfrontal is a short, irregular, subquadrangular bone lying in the angle formed by the frontal and parietal, with which it unites by oblique sutures. It forms the posterior part of the upper margin of the orbit and laterally unites with the *postorbital*, a long, rather slender, quite irregular bone whose anterior extremity enters into the slender arch between the orbit and the lateral temporal fossa, and the posterior extremity into the robust bar between the supra- and lateral temporal fossæ. This latter bar is completed posteriorly by the squamosal, with which the postorbital unites by a broad, overlapping suture. It has a width of about three-fourths of one inch.

Squamosal.—The squamosal has an exceedingly irregular outline owing to its relations both with other bones and with the openings located in this part of the skull. Its anterior margin is incised by both the lateral and supra-temporal fossæ, which divide this part of the bone into three parts. The inner portion forms the proximal margin of the supra-temporal fossa along nearly one-half its length, and unites with the parietal as described in discussing that bone. The central part enters into the arch between the two fossæ, as stated above, while the outer portion extends as a long, gradually tapering wing forming the posterior margin of the lateral temporal fossa along nearly the entire length of that opening. This portion unites along its inferior edge with the quadratojugal and the quadrate in a long, oblique, crescentic, squamous suture. The posterior part of the squamosal borders the posterior half of the large median notch, and forms the rear part of the skull for about one and one-half inches of its width and is then deflected vertically downward to outline the inner border of a small, narrow, obliquely directed notch which pene-

trates the skull margin for an inch. The quadrate also assists in bounding this notch, not only on its outer side, whose entire margin it forms, but also on its forward end and on about one-third of its inner border. Immediately above and in front of this notch the squamosal is hollowed out somewhat to form the opening of the otic capsule, which is also set into the quadrate to about an equal extent.

Quadrate.—This element, from being rather narrow above, widens considerably below and on its lower margin is thickened to form the articulation with the lower jaw. Besides being sculptured on the posterior margin for the reception of the otic capsule and the notch as described above, the quadrate also partially encloses on its anterior margin the quadrate foramen, which pierces the side of the skull slightly above the middle of the length of the quadrate, and is bounded anteriorly by the quadrato-jugal. The quadrate extends on to the lower side of the skull for a short distance and unites with the broad posterior wing of the pterygoid and with the lateral process of the exoccipital along its anterior surface.

Quadratojugal.—The quadratojugal unites below the quadrate foramen with the quadrate in a large squamous suture which lies in the plane of the quadrato-jugal and at right angles to that of the quadrate. A buttress from the quadrate increases the sutural surface and strengthens the union. The quadratojugal is a thin flattened bone. It is almost entirely excluded from the margin of the jaw by the slender extension of the jugal. It reaches the edge just at the point of the jaw and forms about an inch of the margin in this region, although most of this distance is shared with the quadrate. Its upper anterior portion forms the lower posterior margin of the lateral temporal vacuity for about one inch, but is excluded from the margin above by the squamosal.

The posterior margin of the bone is excavated to some depth at about its middle to assist in forming the quadrate foramen, above which the bone again unites with the quadrate.

OPENINGS OF THE SKULL

Nares.—As has been said the nares are situated far backward. In fact they are more than half-way from the anterior to the posterior extremities of the skull, as the distance from the end of the snout to the

anterior point of the nares is fifteen and one-half inches, that from the posterior extremity of the nares to the rear line of the skull is twelve and five-eighths inches. The nares are about one and three-fourths inches in length with an extreme width of five-eighths inch. Behind the point of greatest width they narrow somewhat, and in front of this point they taper quite rapidly forward. In this region the outer wall is cut away, leaving the naris open laterally, as previously described in connection with the nasal. The aspect of the nares is upward in the posterior part, forward and lateral in the anterior portion where the side wall is cut away.

About midway between the frontal and the nares the nasals begin to be elevated and rise gradually to the rear point of the openings. From this point forward they begin to descend, very gently for about half the length of the nares, thence more abruptly to their presumable union with the premaxillæ, which continue the slope an inch or so farther, when it merges into the long, horizontal, upper line of the snout.

Antorbital vacuity.—A short distance behind the nares lie the antorbital vacuities, large ovoid openings with their smaller ends posterior and their long axes directed obliquely backward, upward, and inward in direct line with the axes of the orbits. The length of the vacuity is three and one-half inches and the width two and one-fourth inches. Of the elements which form the margins of this fossa the maxilla is by far the most important, as it makes up the anterior part of the upper margin (just how much is not certainly known), all the anterior border, and the lower border to within one and one-fourth inches of the rear extremity. Here it meets the lachrymal, which bone continues the rear margin and the posterior half of the upper. This leaves not more than one inch of the upper border into which the nasal enters.

The anterior wall of the vacuity is steep, as is also the posterior part of the upper margin, but between these is a narrow depression in the skull, which seems to be natural and which extends obliquely forward and inward about half-way to the nares. Behind the vacuity is a broad, rather deep depression which extends backward an inch from the rear margin and then slopes upward rather steeply toward the anterior margin of the orbit. It drops the lower anterior part

of the lachrymal, and the upper margin of the maxilla in its vicinity is also depressed to form its wall.

Orbits.—One inch behind the antorbitals are the orbits. These are considerably smaller than the antorbital vacuities, as their greatest length is two and three-eighths inches, while their width is one and five-eighths inches. The aspect is upward and outward. The outline is ovoid, with the smaller curve anterior, and the axis points slightly outward and downward. The frontal forms the upper median border, the prefrontal extends thence forward almost to the anterior limit, and the lachrymal contains the narrow curve of the extremity and extends along about one-third of the outer margin. Behind this the upper limb of the jugal enters into the border for another third of its length and meets on the narrow bar between orbit and lateral temporal fossa with the postorbital, which completes the margin to the posterior extremity. From here the postfrontal completes the circuit. The bones forming the inner border of the orbit are turned upward along their margins and form a thickened wall elevating the orbit and giving it a more outward aspect.

Lateral temporal fossa.—The upper line of the lateral temporal fossa lies about behind the middle of the orbit and the cavity extends forward and downward at an angle of about 45° with the axis of the skull to a point almost opposite the shorter axis of the orbit. It is subquadrangular in outline, but the upper posterior angle is extended into a tongue-like embayment which is excavated into the squamosal for a short distance. The length of the fossa is three inches and its width one and three-fourths inches.

The anterior and posterior walls are practically straight and nearly parallel, with a slight divergence, especially at the lower end. The lower margin is slightly concave and its general trend is about at right angles to the lateral margins.

The upper margin is formed in part by the squamosal, which extends above the vacuity as a bar about three-fourths inch wide. Anteriorly this unites with the postorbital and each makes up about one-half of the arch. The postorbital also extends around in front of the fossa and unites with the jugal to form the narrow bar separating the vacuity from the orbit. The jugal also forms the entire lower border to the point where it begins to rise to the posterior margin.

This curve is formed by the quadratojugal, and immediately above this the squamosal enters the margin and continues its outline to the upper border.

Supratemporal fossa.—Lying above the lateral temporal is the supratemporal fossa, much smaller than the lower opening and, unlike the other openings of the skull, facing inwardly, and that in a plane which has a very high inclination. In order to adapt itself to this condition the parietal is in this region deflected downward and forms the floor of the fossa with an outward slope of about 30°. The result is the irregular, suboval depression of triangular section described above.

The anterior margin of the fossa is formed by the parietal, with the exception of the outer angle. The parietal also forms a little more than one-half of the inner border, and the squamosal forms the remainder. On the outer border the squamosal forms the margin for at least two-thirds of the length of the fossa. The boundary is completed by the postorbital, which extends to the anterior margin to meet the parietal.

The fossa measures two and one-half inches in length by three-fourths inch in extreme width, in its anterior portion, though in the posterior region it narrows to a width of one-fourth inch. In shape it is a narrow, irregular ovoid, almost gourdlike in outline, as the narrow posterior part curves slightly upward in characteristic fashion. The plane in which the opening lies is not parallel with the median line, but diverges posteriorly at an angle of about 20° along the anterior two-thirds of its length; thence the divergence suddenly increases, approaching 55°.

Quadrate foramen.—One of the smallest apertures of the skull is the quadrate foramen, situated, as previously described, between the quadrate and the quadrato-jugal, about midway in the height of the former bone. It is subcircular in outline and has a diameter of about three-fourths inch. In the natural condition of the skull the opening must have faced almost directly upward.

Another opening of the skull, but one which is imperfectly closed, is the small notch in the posterior margin already mentioned. It is hollowed out of the quadrate in large part, although the squamosal forms part of its posterior margin. It lies in the upper portion of

the quadrate above and behind the quadrate foramen. It has a height of three-fourths inch, with a maximum width of five-eighths inch, at its lower, open end.

Otic capsule.—The ear opening is about the same size as the quadrate foramen and lies almost directly above it and separated from it by seven-eighths inch of bone. It is irregularly oval in outline with a height of seven-eighths inch and a width of five-eighths inch. The axes of this opening, and of the small notch which lies below and slightly behind it, lie in the same line, and the two openings are so close together that their margins are confluent.

Within the skull the ear cavity enlarges slightly and extends inward to a depth of seven-eighths of an inch. At the bottom of this subspherical cavity a smaller opening three-eighths by one-fourth inch leads into the cranium through the large cavity between the roof and the floor of the skull. The angle at which the ear opening enters the skull is about 55° from the median line of the skull, similar to that formed by the posterior end of the supratemporal vacuity.

So far as can be ascertained this is the first time this opening has been figured and described. Fraas does not show it in his illustrations of *Belodon kapffi* and *Mystriosuchus planirostris*, nor does Cope figure it in his illustrations of *Belodon buccros*. Von Meyer in his illustrations of *Belodon kapffi* shows an opening in the skull which at first sight appears to correspond with this one, but on further examination it proves to be the posttemporal fossa. Neither is the opening shown on McGregor's excellent illustrations of *Mystriosuchus planirostris* and other forms, given in his recent paper on the Phytosauria.

THE UNDER SURFACE OF THE SKULL

This surface presents, in general view, a long triangular depression which extends from the anterior portion of the snout backward as far as the basipterygoid processes of the basisphenoid. This depression is very narrow where contained by the premaxillæ, but widens gradually in the posterior part of these bones and behind them, until it attains its greatest width opposite the anterior portion of the transverse bones. It is bounded laterally by the premaxillæ and maxillæ, postero-laterally by the transverse bones and posteriorly by the short, transverse, wedge-like processes of the pterygoids and

by the basisphenoid. It is roofed by the premaxillæ, a little of the maxillæ, the palatines, pterygoids, and vomers. Three openings pierce it—the paired internal nares and the presphenoidal opening. Behind it medially lies the strong framework of the brain-case, and on either side the large depressions inclosed by the quadrates, quadrato-jugals, and jugals, and pierced by the lateral temporal fossæ and the quadrate foramina.

Where contained by the premaxillæ the trough is bounded on either side by a rounded ridge outside of which are the teeth sockets. This ridge has already been mentioned in connection with the general description of the skull.

FIG. 4.—Cross-section of premaxilla eight inches from extremity of snout.

The end of the snout bears two large teeth on each bone, then a smaller one, separated from them by about one-fourth of an inch. Between this tooth and its nearest neighbor to the rear is a space of three-fourths inch. The other teeth are closely set—not over one-eighth inch apart in most cases—and increase in size gradually from front to rear. The total number on each side is thirty-six, of which twenty are on the premaxilla, the remainder on the maxilla. With one exception all the teeth have been lost and the sockets filled with the sandstone matrix. The single tooth which remains is the second from the rear. It has been somewhat flattened by crushing, but its average cross-section is seven-sixteenths inch. It contains within its cavity a younger small tooth. The teeth of this specimen were apparently all of circular cross-section, resembling those of Fraas's *Mystriosuchus* rather than those of von Meyer's *Belodon*. They must have pointed obliquely outward.

The premaxilla extends somewhat farther back on the under surface than above, as in the former region it has a length of eighteen and one-half inches. Along the last six inches of this distance it is excluded from the margin of the jaw by the maxilla.

Maxilla.—On its lower side the maxilla presents a flat surface from which spring the rather large teeth of this portion of the jaw.

At its anterior extremity this surface is not over three-eighths inch wide, but at its widest extension, at the thirty-fourth tooth, it is one inch across. Back of the last tooth the bone narrows abruptly. About opposite the posterior end of the premaxilla the dentiferous surface of the maxilla begins to be depressed below the palate and this depression increases until opposite the rear teeth it is about one inch. Just behind this region a rounded buttress-like process passes down the inner surface of the maxilla nearly to the edge of the jaw. It may be that the jugal forms the upper part of this buttress, but this is not known. The process is pierced by a small foramen which extends nearly parallel to and about one-half inch above the edge of the jaw. The purpose served by this foramen is uncertain.

Between the twenty-eighth and thirty-third teeth the maxilla bears an obtusely triangular extension which lies perhaps three-fourths inch above the dentiferous margin and enters into the lateral portion of the bony palate.

Palatine.—The anterior limit of this element is not positively known, but its relations with the premaxillæ are believed to be about as indicated in the figure. Posteriorly it widens as the maxilla narrows and reaches its extreme width—one and one-half inch—opposite the posterior limit of the internal nares. Behind this point it tapers gradually, chiefly by being cut away on the outer edge, and leaves the maxilla more and more as it passes backward. Its extreme length is probably six and one-half inches. It is united with the maxilla along the outer edge back to the line of its greatest width, but from here to the posterior end the two are separated by the transverse (ectopterygoid) with which the palatine unites by a roundly serrate suture. The two bones separate slightly about midway along the suture, and leave the narrow palatine vacuity between them. Along the inner margin the palatine unites with the pterygoid as far forward as the internal naris, whose entire outer margin it is believed to form. It probably overlaps the maxilla somewhat in its anterior portion as is apparently true of the European belodonts.

The palatines lie at a somewhat lower level than the pterygoids and so leave between them a cavity in the palate in which lie the pterygoids and vomers. The inner edges of the palatines are turned vertically upward to unite with the pterygoids. It is probably the

ridge thus formed of which Cope speaks in his description of *Belodon buceros* when he says that the palate has a strong ridge on each side so as to be grooved (*Proc. Am. Phil. Soc.*, Vol. XXIV, 1887, p. 217).

Transverse.—This is an irregular bone the posterior part of which originally was directed vertically downward, while the anterior part is turned over at right angles and lies horizontally between the maxilla and palatine. The bone has been somewhat displaced from its original position by pressure. Across its widest portion it measures one and three-eighths inches, and its thickness in this same region is five-eighths inch. Farther forward, where the bone is turned over, its breadth is seven-eighths inch and diminishes anteriorly, while its thickness is seven thirty-seconds to nine thirty-seconds of an inch. The anterior part has been broken away, but the full length must have been three and three-eighths inches. Its anterior part united along the outer edge with the maxilla, along the inner with the palatine. The posterior vertical portion united along its whole outer face for the rear one and one-fourth inches with an extension of the pterygoid. The transverse probably touched the above-mentioned buttress of the maxilla.

Apparently the separate existence of this bone was not recognized by von Meyer in describing his specimens of Belodon. In discussing *B. kapffi* (*Paleontographica*, Vol. X, p. 234) he says that the anterior end of the pterygoid becomes pointed and extends as far forward as the third alveola of the maxilla with which bone it unites outwardly, while inwardly the union is with a bone which may be the palatine, and with which it bounds a sharp oval opening 26^{mm} long and $6\frac{1}{2}^{mm}$ broad (the palatine vacuity). He also states that this bone, together with the jugal, which it touches, forms the anterior angle of the temporal fossa. These statements apply exactly to the transverse, hence it is certain that von Meyer did not observe the suture between the transverse and the pterygoid. Of what he considered the large area of the palate to consist is not clear, but probably he thought that the palatines extended to the median line. This has been shown not to be the case, however, since they are widely separated by the pterygoids and vomers. Cope does not mention the transverse in his description of *Belodon buceros* (*Proc. Am. Phil. Soc.*, Vol. XXIV, 1887, p. 217), although he recognizes the presence

of the pterygoids in the roof of the palate, which von Meyer did not do. Cope (*Syl. Lect. Vert.*, p. 72) figures the transverse, but his figures do not show any sutures.

E. Koken discusses *Belodon* briefly in his paper on *Thoracosaurus macrorhynchus* in *Zeitschr. d. Deutsch. geol. Gesellschaft*, Jahrg. 1885, pp. 763–65. He recognizes the separate existence of the transverse in the following statement, which he makes under heading 4:

> Zusammen mit den Palatinen und Transversen umschliessen sie [Pterygoids] schmale Gaumenlöcher, von deren Umgrenzung der Oberkiefer ausgeschlossen ist und die denen der Crocodiliden gar nicht gleichen, sondern ganz auf Lacertilier herauskommen. Auch das starke Vorspringen der Ossa transversa ist Eidechsencharacter.

The transverse is recognized as a separate bone by McGregor in his paper already quoted, where he describes and figures the bone. His illustrations give an excellent idea of the form of the transverse and of its sutural relations. McGregor, however, omitted mention of Koken's article cited above, and does not include it in his bibliography. But since the latter's paper appeared many years previous to that of McGregor his description of course has priority as being, so far as is known to the writer, the first recognition of the element under discussion.

Pterygoid.—The pterygoid may be said to consist of three parts: first, the broad, thin, flat bone which forms a considerable part of the palate from the internal naris back almost to the rear end of the transverse; second, the short, almost vertical lateral extension already mentioned as united to the transverse; and third, a long posterior wing which unites with the quadrate. The entire length of the bone is seven and one-half inches and the greatest width, that across the lateral wing, must be about three and one-fourth inches. The anterior extremity forms the outer half of the posterior border of the internal naris and extends for perhaps one-half inch along the outer margin. The bone widens gradually backward for three inches and then gives off the lateral extension. The anterior portion is terminated behind very abruptly by a sharp-edged, vertical, transverse process which marks the beginning of the posterior wing. At first the lateral wing is only five-eighths inch wide, but it broadens

distally so that that part which unites with the transverse has a width of one inch. It bears on its outer free surface a rounded vertical ridge which adds considerable strength to the bone. It is on the inner face of this extension that the transverse is attached.

The posterior wing begins with the vertical process referred to, which has a height of seven-eighths inch and an extent across the palate of one and one-eighth inches, and merges with the lateral wing. The posterior wing forms a broad, nearly vertical plate. Its upper edge comes in contact with the lower part of the cranium. The lower edge is thickened and presents a broad surface very much as this element does in *Amblyrhynchus*. The quadrate unites with the pterygoid along the entire posterior border of the latter bone. This portion of the pterygoid, as indeed the entire bone, presents strong lacertilian affinities, and resembles the bone as found in lizards and mosasaurs much more than that in crocodiles, where the quadrate occupies the space here taken by the pterygoid.

The vertical transverse processes may be taken as marking the posterior boundary of the palate, although between and partly behind them is an opening into the interior of the skull, which may belong to the palatal region.

Koken, in his paper to which reference has already been made, states that the pterygoids *scarcely* come in contact. Whether by this he means that they *do* meet is not clear, but they certainly do not do so in the specimen studied. Here they are separated by the *vomers*, which extend from the posterior wings of the pterygoids forward to the nares and between these as much-narrowed bones. It is probable that they again widen in front of the nostrils and here meet the palatines laterally and the premaxillæ anteriorly, a short distance, perhaps one-half inch, in front of the end of the nares. The maximum width of the vomers is five-eighths inch.

Cranium.—The brain-case is very small, measuring not over two and one-half inches from the opening of the foramen magnum to the beginning of the olfactory canal, and about one and one-fourth inches in transverse diameter, external dimensions. The roof is formed by the extreme posterior portion of the frontals, the parietals, and the supraoccipital. The lateral walls are composed of the alisphenoids, the proötics, the inferior processes of the parietals, and the

exoccipitals. The opisthotics may exist coössified with the exoccipitals as in other reptiles, but this is not determinable. The bones forming the floor are the alisphenoids, which are united in their anterior parts only, the basisphenoid and the basioccipital. A small spatulate bone which is attached to the lower margin of the posterior por-

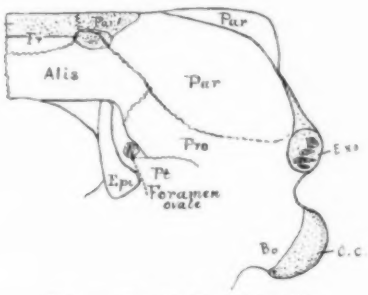

FIG. 5.—Cranine bones from side.

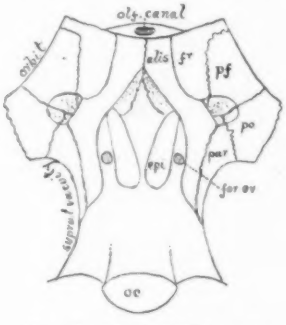

FIG. 6.—Bones of brain case.

tion of the alisphenoid and thence extends downward and slightly posteriorly to unite with the pterygoid, is here considered as the *epipterygoid*. In shape and mode of attachment it occupies a position intermediate between the long slender epipterygoid of the lizards and the short, solidly attached (so-called) epipterygoid of the modern crocodiles. Instead of there being only a small foramen between the epipterygoid and the cranium, as in the crocodile, a large space exists beneath the epipterygoid, more like the condition in *Amblyrhynchus*, for example. It is probable that in life this space was still larger than at present, and that it has been reduced by crushing. Just in front of the epipterygoid is the opening for the III, oculo-motor, and VI, abducens, nerves, and behind it is the fenestra ovale. The foramen magnum is oval in outline and quite large. Its floor is formed by the basioccipital, its walls by the exoccipitals, and the roof by the supraoccipital. The brain-case is continued

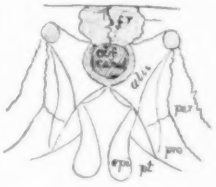

FIG. 7.—Cross-section through rhinencephalic canal.

anteriorly by the olfactory duct, formed by the frontals above and the alisphenoids below. This duct has a diameter of three-eighths inch. Its length is unknown, as the anterior part is concealed in the matrix. It presents a marked contrast to the condition in modern crocodiles, in which its place is taken by a shallow trench and the alisphenoids are not continued forward and do not meet in the middle line. No other openings from the brain-case can be made out because of the presence of matrix where they might be expected to occur.

Of the lower elements of the cranium the most anterior is the *alisphenoid*. This bone is of irregular outline, thin and curved in its front portion to encircle the olfactory lobes. Behind it sends outward and upward a strong process which rests in a depression in the under surface of the postfrontal and postorbital. To the rear the alisphenoid unites with the downward extension of the parietal above and with the proötic below, by oblique sutures. The lower margins of the alisphenoids gape in the posterior region and it is here that the neural foramina occur and that the epipterygoid is attached. As already indicated the anterior portion is concealed.

Only the anterior part of the proötic is exposed and this is seen to be united with the parietal above and the alisphenoid in front. The lower anterior margin is free and borders the foramen ovale. Below this it unites with the pterygoid for a short distance and its lower posterior border meets the exoccipital.

It seems probable that the *basisphenoid* occupies a relation similar to that in the crocodile, that its upper portion is covered by the pterygoid and that the alisphenoid passes downward on the inner side of the pterygoid and epipterygoid to unite with the basisphenoid.

In shape the basisphenoid is very irregular. Where it meets the basioccipital the two bones form a strong transverse ridge, of which however the basioccipital forms only a small part. Anteriorly it sends off the strong downward and forward-reaching basipterygoid processes. Between and above these a vertical rostral plate forms an incomplete septum called by Dr. W. J. Holland the presphenoid in *Diplodocus*. Posteriorly and superiorly the basisphenoid probably unites with the posterior process of the pterygoid and with the exoccipital.

The *basioccipital* forms the chief part of the short stout occipital

condyle. The relations with the basisphenoid have already been mentioned. It is evident from the oblique position of the condyle that the animal held its head at an obtuse angle with the body, very much, probably, as Dr. Holland has figured the dinosaur *Diplodocus carnegiei* in Fig. 1 of his paper on the osteology of *Diplodocus*.

The *exoccipitals* form a little of the condyle, most of the floor and all of the side walls of the foramen magnum, but unlike the condition in the crocodiles and dinosaurs they are widely separated above as in *Amblyrhynchus* and the mosasaurs. Outwardly they have a subcircular cross-section and distally give rise to the long, flattened paroccipital processes which buttress the under surface of the skull and along which the inferior part of the quadrate is attached for some distance. The inferior processes of the parietals probably touch the exoccipitals along their upper edges for some distance.

The *supraoccipital* is roughly triangular as seen from above, with the apex anterior, and all three sides slightly concave. Its upper surface is also quite concave and slopes backward rather steeply. It forms a floor for the anterior part of the deep median sinus previously mentioned. The bone has a width across its base of two and one-fourth inches and its length along the median line is about one and one-half inches. It unites with the exoccipitals by horizontal sutures and thickens along its margins to unite with the parietals in strong vertical sutures.

OPENINGS ON THE UNDER SURFACE OF THE SKULL

Internal nares.—These are the most anterior openings on the palatal surface. Unfortunately they have been almost obliterated in the crushing which the skull has undergone and only the posterior portion of one naris is now visible. This has a width of about five-eighths inch. Its probable anterior dimensions are indicated in the figure. The length cannot be greater than two and one-fourth inches and may be somewhat less than this. The nares are separated by the vomers, which also form part of their posterior borders. These are continued by the pterygoids, and the palatines enclose the openings on the sides. The vomers are thought to form the anterior borders. The internal nares are not, like those of *Belodon*, placed beneath the external, but lie entirely behind them. The anterior

limits of the inferior openings must lie at least one and one-half inches posterior to the rear border of the superior nares.

Palatine foramina.—The small palatine vacuities follow in order. They are not over one inch in length by one-fourth inch in width, and as has been stated are enclosed by the palatines and transverse bones.

In the median line there exists a cordiform opening with a length of one and three-eighths inches and a maximum width of one and one-eighth inches. The apex of this opening is directed anteriorly and separates the vomers for a short distance. Behind the vomers the pterygoids bound the opening. The basipterygoid processes of the basisphenoid lie below and behind the opening; whether they form part of its margin is not known. The vertical anterior plate of the basisphenoid perhaps partly divided this opening in life, but if so it has since been forced to one side.

Posttemperal fossa.—Above the proximal portion of the exoccipital lies the posttemporal opening. As seen from behind this is a small opening nearly an inch long and one-fourth inch high. Immediadiately above the exoccipital the fossa is roofed by the squamosal; in front of the exoccipital it pierces the roof of the mouth and communicates with the great cavity of the skull. On the outer side the border is formed by the quadrate behind and the pterygoid in front. The anterior border is probably formed by the pterygoid and the posterior wing of the parietal, which also forms the inner border.

Infratemporal fossa.—This forms a large irregular opening on the under surface, bounded proximally by the pterygoid and palatine, distally by the quadrate, quadratojugal, jugal, and maxilla.

THE LOWER JAW

Only the posterior part of one mandible is present, but this shows strong belodont affinities and differs markedly from that of the crocodiles. In general outline it resembles the mandible of *Belodon plieningeri* figured by von Meyer (*Paleontographica*, Vol. XIV, Pl. 23). The crest of the surangular is much higher than in the Crocodilia and the portion behind the articular surface is much shorter than in that order. It probably does not extend more than an inch behind the

articulation. The external fenestra is quite elongate though its exact limits are unknown. The probable outlines are indicated in the figure. Only a portion of the posterior margin of the internal fenestra remains, together with the lower margin of the small internal mandibular foramen. None of the symphysis is present.

Owing to the condition of the mandible but few sutures can be made out. However, that between the *articular* and the surangular on the broad, vertical posterior face of the jaw is clearly distinguishable. The outlines of the posterior portion of the angular are also quite distinct. The articular forms the inner two-thirds of the articulation with the quadrate, while the outer third is formed by the surangular. The articular also forms nearly all of the transverse vertical area on the posterior extremity previously mentioned. At the inner border of this area is given off a strong, subrectangular process which is widely separated from the inner face of the jaw and extends nearly parallel with it. The main part of the articular extends forward for some distance, forming the lower margin of the internal fenestra. It may extend as far forward as the internal mandibular foramen, as stated by McGregor to be true in *Phytosaurus*, but this cannot be determined.

Angular.—This element is exposed for a width of about an inch on both sides of the ramus, whose lower margin it forms. It probably forms the posterior angle of the jaw and constitutes its margin for a considerable distance under the fenestræ.

Surangular.—The surangular forms nearly all the outer face of the mandible in its posterior part and makes up the high crest of the jaw, besides entering into the articular surface which meets the quadrate. It is ornamented a little above the middle of its height by a strong, nearly horizontal ridge, slightly concave upward, which starts below the articulation, where it has a width of nearly one-half inch. It narrows anteriorly and becomes quite sharp before it disappears.

The limits of the *splenial* on the inner surface and those of the *dentary* on the outer cannot be determined. Probably they correspond with those of *Belodon* and *Mystriosuchus*.

The outer surface of the mandible is quite rugose in its hinder part and somewhat so farther forward. The rugosities consist

chiefly of small, rounded eminences, with some ridges. The inner surface is rather smooth.

With regard to the nomenclature of the mandible it may be stated that the one generally accepted is here used. As is well known Baur (*Anat. Anz.*, Vol. XI, 1896) attempted to modify the classification of the bones by applying the name of angular to a long splint-like element in front of the articular instead of to the bone previously designated by this name. This necessitated a shifting of names and Baur called the angular "splenial" and the splenial "presplenial." Baur's primary mistake lay in his accepting the turtle as the basis of nomenclature while the original nomenclature was based on the crocodile.

Kingsley has since (*Am. Nat.*, 1905, pp. 59 ff.) corroborated Baur's observations as to the origin of these bones and, taking the crocodile as the standard, has retained the names of the bones as originally given by Cuvier and Owen. Thus he designates the so-called splenial of the turtle of authors, the splenial of Baur, the "dermarticular."

Williston had, however, previously discussed this bone from the plesiosaurs ("North Am. Ples.," *Field Col. Mus., Geol. Ser.*, Vol. II, No. 1, 1903, pp. 29–32) and had given it the name of prearticular. This name should then have priority over that of Kingsley. The prearticular is apparently absent from the crocodiles, while it is a distinct bone in plesiosaurs, dinosaurs, turtles, and some other early reptiles.

THE ILIUM

This bone presents features which distinguish it quite markedly from that of *Rhytidodon* as figured by McGregor. The acetabulum is quite broad and must have been quite largely contained by the ilium. Above the acetabulum is a strong process which rises fully two inches above the depth of the cavity. It is of triangular cross-section and is formed by the junction of three ridges, two of which bound the acetabulum and form its upper walls, while the third extends obliquely forward toward the upper anterior corner of the bone. This ridge is very strong where it rises up to aid in forming the process, but it thins distally and does not quite reach the anterior extremity. The upper anterior process has a rounded outline and, unlike *Rhytidodon*, its

upper border is quite elevated and is limited by a broad shallow sinus from the remainder of the upper margin of the bone. The lower anterior process is much shorter and blunter than is that of *Rhytidodon*. Instead of being drawn out to a point it ends in an enlarged, oblique, vertical face of triangular shape. The lower posterior border is rounded and presents a large, roughened surface for the attachment of muscles. The postacetabular process has been broken off but was doubtless similar to that in *Rhytidodon*. The upper border was doubtless somewhat convex, although not so much so as in *Rhytidodon*,

FIG. 8.—Ilium of *Paleorhinus bransoni* Williston.

but as already stated its convexity is interrupted by a broad sinus, giving the anterior part a decidedly concave outline.

On the inner surface the bone is relatively smooth except for the long, shallow trench along its upper part for the reception of the sacrum. This trench is outlined along much of its length by slightly elevated and angular ridges. Below this trench there is also at the anterior extremity of the bone a shallow, ill-defined depression.

The new features which the present study has disclosed may be here summarized. The presence of the otic capsule and its relations and dimensions have been determined. The sutural relations of the palatine, pterygoid, and vomer have been more clearly delineated, and the unsuspected posterior extension of the latter element as far as the presphenoidal vacuity demonstrated. It is believed also that the

elements of the brain-case have been more completely identified than has been possible previously and their relations more clearly made out. The enclosure of the olfactory canal by the alisphenoids, the presence and character of the epipterygoid, here so considered, and the relations of the roof bones and the cranial elements are points which so far as known have not heretofore been noted. It is hoped that these determinations have been made with sufficient accuracy to serve for purposes of future comparison.

Another feature distinctive of this genus, although one mentioned by Dr. Williston in his paper previously noted, is the anterior position of the external nares. The position of the internal nares behind the external also seems to be a new character.

RELATIONSHIPS OF PALEORHINUS

In comparing the specimen under discussion with the belodonts we may adopt here McGregor's division of the group into *Phytosaurus* and *Mystriosuchus*. If we include under the former genus the European forms with high rostrum—*Ph. kapffi* and *plieningeri*—and Cope's species, *Ph. buceros*, these may be dismissed at once, since the differences between this group and *Paleorhinus* are great enough to be considered generic. Fraas in 1896 separated *Belodon planirostris* from the genus and founded a new one, *Mystriosuchus*, for it, because of the great differences in the shape of the snout. The skull of *Paleorhinus* presents similar differences, hence its distinctiveness may be taken for granted. Of Cope's species, *Belodon scolopax*, little can be said since that was based on the anterior portion of a rostrum which, Cope states, is "shorter but much more slender than that in *B. plieningeri*." This gives but slight basis for comparison.

Between *Mystriosuchus* and *Paleorhinus*, however, there appears at first glance to be an intimate relationship. But, upon closer examination, certain features are seen to be widely divergent in the two specimens. In the first place, that part of the skull of *Paleorhinus* which lies in front of the anterior point of the nares is one inch longer than the portion behind this point. In the case of *Mystriosuchus*, on the other hand, the distance from the tip of the snout to the anterior point of the nares is five-sevenths of the entire length of the skull.

Furthermore, the proportions of the skull are quite different. The following table of dimensions will serve to make this clear:

	Mystriosuchus planirostris		*Paleorhinus bransoni*	
Length of skull	33.375	inches	30.500	inches
Width of skull across quadrates	7.875	"	9.750	"
Width of skull opposite middle of orbits	6.625	"	7.250	"
Width opposite anterior extremity of external nares	3.000	"	3.000	"
Length from rear of skull to quadrate	1.500	"	0.300	"
Length from rear of skull to lateral temporal fossa	2.875	"	2.375	"
Length from rear of skull to supra-temporal fossa, anterior extremity	2.875	"	3.700	"
Length from rear of skull to supra-occipital	1.375	"	2.300	"
Length from rear of skull to rear point of orbit	4.400	"	5.000	"
Length from rear of skull to rear point of pre-orbital vacuity	6.750	"	8.500	"
Length from rear of skull to rear point of nares	8.000	"	12.500	"
Length from rear of skull to anterior point of nares	9.500	"	14.625	"
Length from rear of skull to rear point of internal nares	8.000	"	9.000	"
Length of premaxilla	23.250	"	14.750	"
Length of maxilla	7.500	"	12.500	" (?)
Length of nasals	4.875	"	9.000	" (?)
Width of nasals	1.375	"	1.000	"
Length of frontals	2.000	"	4.000	"
Width of frontals	.875	"	1.000	"
Number of teeth on upper jaw	94		72	

There are several other differences, among which may be noted the following: In *Mystriosuchus* the parietals extend backward between the supratemporal openings at the level of the top of the skull for a little less than one inch, while in *Paleorhinus* they extend in this direction two and one-fourth inches, are widely separated, as already described, and meet the squamosals posteriorly to enclose the supratemporals at the upper level of the skull. In *Mystriosuchus* this "parietosquamosal arcade," to use McGregor's term, is considerably depressed and forms a thin plate lying on the paroccipitals. This gives the supratemporal openings and the large median notch quite a different appearance in the two specimens. Several of the openings in the skull are of different shapes in the two individuals, and the

nares particularly occupy very different positions. In the European form their anterior limits lie behind those of the preorbitals, while in *Paleorhinus* the whole of the nares lies considerably in advance of the preorbitals.

The paroccipital processes are much wider in *Mystriosuchus* and cover the parietals. The posterior wings of the pterygoids are, however, much smaller and shorter and leave a large opening which in *Paleorhinus* is filled by the quadrate and pterygoid.

Some of the distinctions mentioned above as well as those indicated in the table of dimensions might be considered as being merely specific, but some are undoubtedly of generic rank. Such are the differences in dentition and relative major dimensions of the skull, in location of the nares, in the position of the parieto-squamosal arcade, and its relations to the supratemporal fossa. These divergences would seem to be amply sufficient to warrant the separation of the individuals into different genera, as has been done.

It is impossible to make a close comparison of this specimen with Lucas' genus *Heterodontosuchus*. This latter was founded on the imperfect anterior portion of a lower mandible, while as before stated the only portion of the mandible of *Paleorhinus* which is available is the posterior part, well behind the symphysis. If one may judge from the upper jaw of *Paleorhinus* there must be some difference in the teeth of the two specimens, since Lucas stated that in *Heterodontosuchus* these are separated only by an extremely thin film of bone, while in *Paleorhinus* they are from one-eighth to one-fourth inch apart. There is evidence also that this is true in the lower jaw.

There is no indication of the "deep narrow groove" which Lucas speaks of as extending "along the side of the jaw." Neither do the teeth seem to have been compressed antero-posteriorly as in Lucas' genus. On the contrary the sockets are quite circular.

On the other hand there are some features in which the two specimens show a close similarity. In both specimens the teeth are set very obliquely in a broad, shallow groove, and the two anterior ones, together with the extremity of the jaw, are enlarged. (In all other forms where known the end of the mandible is enlarged and presumably is so in *Paleorhinus*. The enlargement of the upper jaw is very noticeable.)

It scarcely seems wise under the circumstances to make any positive statement regarding the generic identity or separateness of these two specimens without comparison of all the material available, and this has not been possible. There are other nearly perfect skulls in the collection from the Popo Agie beds quite different from the present one which have not yet been studied. Dr. Williston is doubtful as to the distinction, but inclines toward the belief that they belong to the same genus. See his paper on this specimen previously quoted.

It is chiefly because of the marked differences between the ilia of *Rhytidodon carolinensis* as figured by McGregor and of the specimen in hand, differences which are believed to be generic in value, that the specimen is considered as of another genus. These differences may be briefly summarized here. They are: the absence of the transverse ridge from the outer face of the ilium of *Rhytidodon* and its presence in that of *Paleorhinus;* the angularity of the processes in *Rhytidodon* contrasted with their roundness and broadness in *Paleorhinus;* the convex upper edge of the bone in *Rhytidodon* and its general concavity in *Paleorhinus* and the greater size and strength of the central process in *Paleorhinus*.

A comparison of the skulls of the two genera is somewhat difficult owing to the incomplete condition of the skulls of *Rhytidodon*. The distinction which impresses itself most strongly upon the attention is that between the proportions of the skulls. McGregor states (p. 59) that the prenarial portion of the skull of *Rhytidodon* must be two-thirds the entire length. In *Paleorhinus*, on the other hand, the pre- and postnarial portions are nearly equal—the prenarial portion is one inch the longer.

Another distinction between the two genera is the long backward projection of the squamosal region over the quadrates in *Rhytidodon*, while in *Paleorhinus* the quadrates and bones associated with them extend almost as far backward as does the upper surface of the skull.

Further, in *Rhytidodon* the external nares are situated over the internal and lie opposite and above the middle of the antorbital vacuities. In *Paleorhinus*, however, the external nares lie far in front of the internal openings, which are situated opposite the middle of the antorbital vacuities. The external nares thus occupy a position well in advance of the antorbital vacuities. This difference is due to the

difference in the relative position of the external nares in the two genera, since the other openings occupy similar positions in both.

There are also some minor differences in the shapes of the various openings of the skull.

The thanks of the writer are due to Dr. S. W. Williston, whose kind personal supervision and interest have made this work possible. Dr. Williston has not only given the study his attention during its prosecution and the benefit of his intimate knowledge of reptilian types, but he has also criticized the completed paper. The writer's thanks are also due him for permission to make use of the material upon which the paper is based.

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ABBREVIATIONS USED IN FIGURES

Alis.,	alisphenoid.	Ot.,	otic capsule.
Ang.,	angular.	P.,	palatine vacuity.
Ao.,	antorbital vacuity.	Pal.,	palatine.
Bo.,	basioccipital.	Par.,	parietal.
Bp.,	basipterygoid, processes of	Pf.,	postfrontal.
Bs.,	basisphenoid.	Pm.,	premaxilla.
D.,	dentary.	PO.,	antorbital vacuity.
Ect.,	ectopterygoid.	Po.,	postorbital.
E. M. F.,	external mandibular fenestra	Prf., pf.,	prefrontal.
E. N.,	external nares.	Pro.,	Proötic.
Epi.,	epipterygoid.	PS.,	presphenoidal vacuity.
Exo.,	exoccipital.	PT.,	posttemporal vacuity.
Fr.,	frontal.	Pt.,	pterygoid.
I. T.,	infratemporal vacuity.	Q.,	quadrate.
J.,	jugal.	Q F.,	quadrate foramen.
L.,	lachrymal.	Qj.,	quadratojugal.
L T.,	lateral temporal vacuity.	S.,	supraoccipital.
M.,	maxilla.	Sur.,	surangular.
N.,	nasal.	Sq.,	squamosal.
Na.,	internal nares.	ST.,	supratemporal vacuity.
O.,	orbit.	V.,	vomer.
O C.,	occipital condyle.	III, V, VI,	openings of III, V, and VI nerves.

THE CRYSTALLINE ROCKS OF THE OAK HILL AREA NEAR SAN JOSÉ, CALIFORNIA

E. P. CAREY AND W. J. MILLER

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INTRODUCTION

The Oak Hill area is situated about four miles south of the city of San José, in the Santa Clara Valley, California. On the north of

this area is a quarry from which the city of San José obtained road material for a number of years. The road material consisted largely of diorite intruded into partially serpentinized peridotites and pyroxenites, with which they are very intimately associated.

The area mapped and studied in detail comprises nearly three square miles, namely the group of hills south of the Oak Hill Cemetery and west of the Monterey Road. This group of hills rising out of the Santa Clara Valley will be designated in this paper as the Oak Hill area, while the term "Quarry Hill" will be applied to the hill in which the quarry is situated.[1] The prevailing rock of the region is serpentine, which shows unmistakably its origin from peridotite. The transitions have been most carefully studied in and near the quarry. Not less interesting, however, are the pyroxenite and gabbro occurrences which are intimately associated, the pyroxenite showing every step in the transition into serpentine, on the one hand, and apparently into the different types of gabbro, on the other. Several diorite dikes occur cutting through the more basic rocks, and glaucophane schist has been found in a number of excellent exposures.

The region is further remarkable for the extent and variety of intrusives of more acid rocks, gabbroid and dioritic in character.

Sandstones and radiolarian jaspers make up a small part of the area and are the only rocks of sedimentary origin.

TOPOGRAPHY

The Oak Hill area comprises a group of well-rounded crests, part of an old erosion plain rising out of more recent valley alluvium which surrounds the hills on all sides. These hills really form an integral part of the Mount Hamilton Range, and are practically connected with this range by a low line of peridotite-serpentine hills, sometimes known as the Los Lagrimas Hills, which outcrop to the southeast of the Monterey Road.

Of the nine fairly well-defined crests of the area, the highest is 438.5 feet above the level of the valley. The trend of the crests is approximately northwest and southeast, which corresponds to the general strike of the Coast Ranges in this region.

[1] Work on the rocks of the Oak Hill area was carried on during the two years 1901 and 1902. The petrographic investigations were carried on at Stanford University under the direction of Dr. J. P. Smith.

The surface of the serpentinized area is hummocky and often almost destitute of soil, which character aids in determining the areal extent of the serpentine.

THE DIORITES

Occurrence and relations.—The Diorite occurs in dikes intrusive into the older pyroxenite—peridotite rocks and gabbros. The best exposure is to be found in the quarry. The dikes here constitute

FIG. 1.—North face of Quarry Hill, showing diorite dikes in pyroxenite, gabbro, and serpentine.

two sets: an older set of five nearly vertical dikes, averaging about three and a half feet in width and parallel with each other, intersected by another set of parallel dikes, averaging about four and a half feet in width and dipping toward the northwest.

The relations of these two intersecting sets of dikes are now, since the field-work was done, rather obscure, on account of a talus that is beginning to cover up some of the intersections; but some intersections are still apparent, as is evident from the photograph, and the relative age was plainly evident when the work of quarrying the diorite was in progress.

Both sets of dikes have been faulted after the intrusion, the fault zones being common to both sets of dikes. Three of these fault zones may be seen in the quarry in addition to minor displacements; but the displacement in no case exceeds a few feet. Pyroxenite, gabbro, and serpentine fill the space between the dikes in the quarry. In a cut near the east side of Quarry Hill a large diorite dike in pyroxenite shows spheroidal weathering, where the soft outer layers, which may

FIG. 2.—Banded structure in olivine gabbro—Quarry Hill—common also to pyroxenite and norite.

be easily removed, grade into extremely hard spherical cores. Other fine-grained dioritic dikes may be seen intruded into norite in an open cut on the north side of the top of Quarry Hill. Other scattered outcrops of diorite were found on Quarry Hill and over the north part of Oak Hill area, but no exposures have been observed to the south of the area nor in the Los Lagrimas Hills to the southeast.

Petrographic characters.—The color of the hand specimen varies from a light to a dark gray, while the texture varies from very fine to rather coarse-grained, so that the commonest minerals, plagioclase and hornblende, may easily be seen with the naked eye. One of

the most striking features of the coarser-grained specimens is the prominence of the hornblende crystals which make up one half of the rock. Because of slower cooling, the inner portions of the large dikes are more coarsely crystalline than the outer portions, while the narrow dikes and numerous branching tongues are fine-grained.

Upward of twenty thin sections were examined, and the chief constituents were found to be: plagioclase, hornblende, augite, biotite, and iron-oxide. Plagioclase, chiefly oligoclase and andesine, is, in all cases, the most abundant mineral. It usually occurs in large idiomorphic crystals, frequently twinned according to the albite law. The crystals are always weathered, sometimes almost beyond recognition, especially in the older set of dikes.

Hornblende, rather evenly scattered through the sections, is almost as important as plagioclase. It shows its characteristic pleochroism, and in many cases also its typical cleavage angle of about 124°. Sometimes the hornblende is concentrated into small green patches about the size of a pea.

Orthoclase is a minor constituent compared to plagioclase and usually occurs in irregular grains.

Augite is quite abundant in some specimens, while in others it is entirely absent. It usually appears in well-developed crystals showing a brown color, very slight pleochroism, and characteristic cleavage angles of 87°.

Biotite is a minor constituent, but often occurs in the typical brown patches with fine basal cleavage and strong pleochroism.

Iron oxide occurs as occasional opaque irregular grains in all of the sections examined.

A study of the diorites shows a considerable variation of these rocks among themselves. Some contain very little augite and feldspar while they are very rich in hornblende. Such rocks would readily suggest a similarity to the gabbros in basicity. Other diorites contain much less hornblende, but more feldspar and augite, and are the most acid rocks of the series.

Chemical analysis.—The following is a partial analysis of the typical Quarry Hill diorite furnished by the United States Geological Survey to Dr. J. C. Branner:

SiO_2	51.52
Al_2O_3	23.14
Fe_2O_3+FeO	6.17
TiO_2	0.33
CaO	9.58
MgO	1.64
P_2O_5	trace
Total	92.38

THE GABBROS

Occurrence.—Among the igneous rocks of the Oak Hill area the gabbros are smallest in amount. They occur on Quarry Hill and seem to grade over, on the one hand, into the basic pyroxenite-peridotites and, on the other, into hypersthene gabbro or norite. Among themselves the gabbros are very variable in mineral composition. They range from a typical olivine gabbro to a hypersthene gabbro. There is no evidence of intrusion. On the other hand, the field relations together with the microscopic evidence demonstrate a transition into serpentine. A tunnel into the base of Quarry Hill on the north side penetrates the norite for about seventy-five feet. An open cut on top of the hill immediately above this tunnel shows exposures of the same norite. In the field a distinct gneissic structure is noticeable, which in this phase of the rock is scarcely evident in the hand specimen. Outcrops of the other gabbro are irregularly scattered over Quarry Hill, and none are found over the other parts of the area studied.

Petrographic characters.—The gabbro and norite are granitic in texture and of dark-gray color. The typical gabbro is usually medium grained, while the norite is slightly finer-grained. In the hand specimen the plagioclase, olivine and diallage of the gabbro are plainly visible to the naked eye. The plagioclases with their shiny surfaces and the diallage crystals with their greenish shiny faces appear to be unusually fresh. In the norite the plagioclase and the hypersthene are likewise visible to the naked eye. Here the plagioclase appears slightly more weathered than that of the gabbro. The hypersthene occurs in numerous brown crystals evenly scattered throughout the mass.

In marked contrast to the diorites, the minerals in many of these gabbro-norites are clear and fresh. The list of minerals in this series of rocks includes the following: plagioclase, hypersthene, diallage, enstatite, hornblende, olivine, augite, and iron-oxide. Sometimes all of these may be seen in a single section.

Plagioclase, chiefly labradorite, is the most constant of the minerals present. It occurs in clear glassy plates the crystals being usually well-defined. Twinning according to both the albite and carlsbad laws is common. Sometimes pericline twinning was observed. Olivine and hypersthene are occasional inclusions.

Hypersthene is the second most abundant mineral in the typical norite. Very little, or sometimes none, is present in the gabbro. The hypersthene usually appears as allotriomorphic crystals. The pleochroism from reddish-brown to greenish-yellow to green is very distinct. The hypersthene seems generally rather fresh but sometimes it is weathered to a green serpentinous mineral.

Diallage is the next most common mineral in the typical gabbro, but is less abundant in the norite. It appears as large irregular crystals, often blurred by weathering. In ordinary light it varies from nearly colorless to a light green. The fine striations so characteristic of diallage are well developed. The crystals exhibit a metallic sheen and show no pleochroism. In a few instances twinning was noticed. Plagioclase is often included in the diallage, and very often the diallage has grown partially around the plagioclase, thus showing it to be later in formation.

Enstatite is abundant in some of the gabbros. It always occurs without regular crystal boundaries. The highly characteristic columnar structure and the parallel extinction are well shown.

Hornblende is usually absent from the typical gabbro; it is present to only a small extent in the norite; but in sections from a few outcrops it is so predominant that the rocks may readily be called hornblende-gabbro. In the latter rocks much of the hornblende is badly weathered and is altered to cholorite in green patches. The characteristic cleavage lines making angles of about 124° are very distinct in the primary hornblende. It exhibits a pleochroism from a green to a light yellow. Examples of twinning are also quite common.

Common augite occurs in considerable quantity in the norite, but scarcely any is present in the gabbro. The individuals are allotriomorphic and very irregular in shape, but show the usual cleavage angles of 87°. The pleochroism of the augite is from a colorless to a light brown. It may often be seen perfectly twinned. Some inclusions of olivine were noticed.

Olivine is a constant constituent of all the gabbros. In ordinary light it is colorless, while in polarized light it exhibits the characteristic high relief and strong double refraction. The crystals are usually rounded, but are generally much weathered and blurred. It is often serpentinized along irregular cracks that ramify through the crystals.

Magnetite is found in small opaque patches scattered through all the sections of gabbro and of norite.

Relations of the gabbros.—From a study of the field relations and the examination of a number of thin sections it is evident that the different variations of gabbro are merely local. Some of the gabbros have much olivine—olivine gabbro; some have much hornblende—hornblende gabbro; many of the gabbros have abundant hypersthene—hypersthene gabbro or norite; many have a predominance of diallage—normal gabbro.

The typical norite from the cut at the top of Quarry Hill contains much hypersthene, together with some hornblende and augite, while it contains little olivine and diallage. On the other hand, the typical gabbro contains much diallage, but practically no hypersthene, hornblende, nor common augite. Sections have been examined which show almost perfect gradations between these various kinds of gabbro, thus strongly suggesting that they are phases in the differentiation of the same magma.

Those gabbros which are rich in diallage and poor in hypersthene, hornblende, and augite most nearly approach the pyroxenites, next to be described, in constitution. Those which are rich in hypersthene, hornblende, and augite, but poor in diallage, most nearly approach the diorites. Thus the gabbros which undoubtedly represent the most acid end of the interesting basic series of pyroxenites, peridotites, and resulting serpentines may also be a connecting link between these and the more acid diorites. All the above gradations may be observed within a radius of seventy-five yards of Quarry Hill.

Chemical analysis.—Following is a partial analysis of the olivine gabbro furnished to Dr. J. C. Branner by the United States Geological Survey:

SiO_2	48.11
Al_2O_3	14.67
$Fe_2O_3 + FeO$	6.45
TiO_2	0.15
CaO	17.55
MgO	11.19
P_2O_5	none
Total	98.12

THE OLIVINE PYROXENITE

Occurrence.—This rock occurs mainly in and about the quarry, and is made up essentially of olivine and diallage with some magnetite. The percentage of diallage varies from a few scattered crystals, as in the massive varieties of serpentine, to a rock made up almost entirely of diallage. The olivine is never wholly free from the process of serpentinization, except in the gabbro phase of the rock, and usually no feldspar is present. It is evidently a phase of the serpentine, the difference being chiefly in the relative proportion of the olivine and diallage.

Petrographic characters.—A gneissic structure common to the gabbros is also, in this rock, very perfectly developed, and is accentuated at the surface by weathering. The diallage crystals are generally nearly a centimeter in length and quite uniform in size. Their cleavage surfaces are brassy in appearance, in some cases quite dark. When near the serpentine phase the whole rock becomes dark, resembling the massive serpentine. On the southeast side of the quarry entrance the rock is practically a diallagite, of a greenish-yellow color. On the south face of the quarry this rock contains feldspar and fresh olivine, thus passing into the gabbro phase. The optical properties of the diallage and olivine are the same as in the gabbro.

THE PERIDOTITE-SERPENTINE

Occurrence and associations.—Serpentine forms the greater part of the Oak Hill area and can be traced almost continuously severa

miles along the Los Lagrimas Hills southeast to the Mount Hamilton Range. It is about eleven miles from the serpentine of the New Almaden region described by Becker.[1]

In most respects it is similar to the serpentine of the San Francisco Peninsula, Angel Island, Crystal Springs Lake, and numerous other occurrences in the Coast Ranges; and it is probably identical in age with them. It is associated with radiolarian cherts and sandstones which belong to the formation described by Professor Lawson[2] as San Franciscan, and by Dr. H. W. Fairbanks[3] as Golden Gate.

The serpentine mass here represents an intrusion in the nature of a boss or very large dike. The outcrop reaches a width of one and a half miles. The extent below the surface cannot be determined because in most places it is buried beneath the alluvium which covers the valley floor.

The prevalence of schist about the periphery of the serpentine, together with the fact that the jaspers, where they occur, are frequently contorted and otherwise altered, would suggest that serpentine was capable of affecting to a considerable degree the rocks into which it was intruded; yet this evidence is not conclusive.

Petrographic characters.—The serpentine varies greatly in character. It typically consists of crystals of diallage imbedded in a groundmass varying in color from a light to a dark green, consisting chiefly of the mineral serpentine, in which are numerous grains of magnetite. Enstatite and iron-pyrites are found very sparingly, while a large portion of the slides show residual grains of olivine. The process of serpentinization is also observed in some of the imbedded diallage crystals working in along the cleavage planes from the outside to the center, although this mineral is usually fresh.

This massive phase of the peridotite-serpentine varies in composition from a rock, in which the glistening face of a diallage crystal may be seen here and there imbedded in serpentine, to one made up essen-

[1] *Geology of the Quicksilver Deposits of the Pacific Slope*, Monograph XIII, U. S. Geological Survey.

[2] *Geology of the San Francisco Peninsula*, Fifteenth Annual Report, U. S. Geological Survey.

[3] "The Stratigraphy of the California Coast Ranges," *Journal of Geology*, Vol. III (1895), pp. 415-33.

tially of diallage, the latter presenting an uneven fracture, while the former is a compact rock with a conchoidal fracture.

The mesh structure is common, especially in the compact conchoidal variety, while grains of olivine and minute crystals of magnetite are disseminated throughout the whole mass. The minute crystals of magnetite may be detected in the groundmass by the aid of a pocket lens, and are so numerous that the fine powder of the crushed serpentine will immediately jump to a magnet. These magnetite crystals are chiefly concentrated along the lines common to contiguous meshes, but are at times also found along with serpentine, making up dark anastomosing veins, attaining in some instances half an inch or more in width.

Genesis of serpentine from peridotite.—The structure and mineralogical composition of this serpentine then clearly indicate that it was derived from a basic rock in which olivine was the predominating mineral together with diallage and magnetite. The peridotite from which the serpentine was derived is not found in a fresh condition. It is interesting, however, to note that in the phases of the rock in which diallage predominates we do have a comparatively fresh rock, which fact confirms the igneous origin of the serpentine.

Chromite.—Several somewhat irregular pockets of chromite in peridotite-serpentine occur in the Los Lagrimas Hills, never exceeding a few feet in extent. The relative hardness of the ore in some cases caused it to stand up above the surrounding surface. On this account it attracted attention, and formerly on the Swickard ranch near the Coyote Creek, these occurrences were mined, and the product shipped east. So intimately associated is the serpentine with the chromite that it is difficult to secure from these prospect holes a hand specimen of the ore that does not contain serpentine. It would seem as if the chromite is a product of differentiation from the serpentine.

Cinnabar.—The San Juan cinnabar mine occurs on the Oak Hill area. Here the ore occurs along joint planes and zones of faulting, the impregnations extending some distance from the walls into the serpentine and its alteration products. Extensive mining is not now carried on in this region, though operations are now being conducted in a small way.

At the Silver Creek mine, four miles south of Evergreen, in appar-

ently this same range of serpentine, the conditions are very similar. It would appear that formerly comparatively extensive mining operations were carried on at both these places.

Analysis of serpentine.—The analysis of this serpentine was furnished by the United States Geological Survey at the request of Dr. Branner. The other analyses of Coast Range serpentines are given for comparison.

	I	II	III
SiO_2	37.71	39.60	42.06
Cr_2O_3	.....	0.20	.....
Al_2O_3	1.81	1.94	2.72
Fe_2O_3	10.47	.....	.....
FeO	.....	8.45	2.88
MnO	.....	.....	.....
MgO	35.60	36.90	39.53
Na_2O	(not determined)		
$Ti O_2$	0.09	.....	.....
H_2O	(not det.)	12.91	12.04
Total	85.95	100.00	99.23

I. Massive conchoidal serpentine of the Oak Hill area, by United States Geological Survey for Dr. Branner.

II. Serpentine from Presidio, San Francisco; analyst, Dr. Easter. *Pacific Railroad Reports*, Vol. VI [1855]. (Pt. 2, p. 11.)

III. Serpentine hard sound nodule in crushed matrix; analyst, Dr. F. L. Ransome. ("The Geology of Angel Island," *Bulletin of the Department of Geology of the University of California*, p. 231.)

Analysis No. 1 (United States Geological Survey) confirms the conclusions reached above. The original rock was evidently ultrabasic. The large percentage of iron is doubtless accounted for by the presence of the mineral magnetite, while the mineral serpentine makes up a large part of the remainder of the rock. The proportion of silica to magnesium also approaches that ratio in the pure mineral serpentine, in which 40.42 per cent. of magnesium corresponds to 41.52 per cent. of silica. The evidence is clear that the serpentine is an altered igneous rock. On some of the slopes of the Oak Hill area, where both sandstone and serpentine are exposed, a mechanical mixture of serpentine and sand has been formed.

SLICKENSIDED SERPENTINE

This aspect of the serpentine in most respects closely corresponds to that described by Dr. Palache.[1] The rock is varied in character, being found from a gray to a light green shade, and is quite soft. The plane slickensided faces, often greasy and striated, predominate over curved faces, so that in many places it has a foliated or schistose structure. This phase occurs in rather extensive zones which appear to be fault zones, and also along joint planes in the peridotite-serpentine, which are frequently planes of movement. In some cases the slickensiding has extended out from the joint planes, involving the peridotite-serpentine until it remains as a core in the center of the slickensided variety.

While at the Potrero the massive facies is very subordinate in amount, in the Los Lagrimas Hills and the Oak Hill area the reverse is the case, and the bowlders are represented in a few places in the beginning stages of formation.

MOTTLED SERPENTINE

Associated with the massive green serpentine in and about the quarry occurs a light green facies in which roundish light colored areas are found in the green or grayish-green variety making up about half the rock, and giving to it a very striking and mottled appearance. The light spots vary in size from points barely visible to the size of a hen's egg or even larger. The microscope shows that the mesh structure is present in the least decomposed parts of the white areas and is continuous from the contiguous green part, in some cases gradually disappearing as the center of the white area is approached. Small magnetite crystals are also present, though not so numerous, and have a similar distribution. Often small cores of the greenish serpentine occur within the white areas, frequently near the center.

Qualitative analysis demonstrated abundant silica and magnesium, indicating that it is essentially magnesium silicate, and that it is derived from the mineral serpentine by secondary changes, possibly accompanied by the leaching out of iron. The frequent occurrence of this white material in veins, and the fact that the surface of the

[1] "The Lherzolite Serpentine and Associated Rocks of the Potrero," *S. F. Bulletin of the Department of Geology of the University of California.*

greenish variety weathers to this same product, would tend to confirm this view.

These patches disintegrate on exposure more readily than the massive green variety, and in some instances accentuate the very irregular and fantastic forms that result from surface weathering.

This change of the mineral serpentine to magnesium silicate, which is common in serpentine areas, seems to be an intermediate one, and frequently precedes the release and subsequent deposition of silica and the taking-up of carbon dioxide, thus forming a rock made up of carbonates and various forms of silica, together with compounds of iron, etc. Such a rock occurs quite abundantly in the vicinity of the Oak Hill area, and will now be described.

"SILICA CARBONATE SINTER"

Its occurrence in the serpentine appears to be somewhat sporadic, and there is no fixed evidence to indicate that it is either an inclusion, a dike or a vein. On the other hand, it seems to bear relationships with the serpentine with which it is found and into which it grades. At times it occurs in the form of a dike or vein, but may be irregular in outline. The alteration in some cases is so complete that the rock has many characteristics of a vein.

Petrographic characters.—Professor Lawson described what is evidently this same rock under the tentative name "Silica-Carbonate Sinter,"[1] and his description applies so well that I quote it here:

> Petrographically the rock is an exceedingly irregular and intricate mixture of silica in the form of opal and chalcedony and carbonates of lime, magnesia, and iron. The silica is present usually in the form of a mesh-work of veinules, which, however, do not seem to fill fissures in the carbonate, but to be of contemporaneous formation with it. These veinules anastomose, but do not commonly intersect, and they vary greatly in their thickness. In weathering, the carbonate of iron yields an abundant ochre, the other carbonates are leached out, and the silica remains as a honeycombed mass, giving rise to exceedingly irregular and fantastic, pitted and cavernous forms, which project ruggedly above the general surface. It is difficult to get a fresh mass of the rock quite free from the yellow ochre. In the least decomposed specimens the carbonates are seen to have the crystalline texture of marble with a yellowish color. Occasionly there is a bright green strain apparent in the rock which may be a silicate of iron.

[1] "Geology of the San Francisco Peninsula," *Fifteenth Annual Report of the U. S. Geological Survey*, p. 435.

In a recent letter to Mr. Carey referring to the genesis of his rock, Professor Lawson says:

> I have seen a good deal of that so-called "Silica-Carbonate Sinter," since I wrote my paper on the geology of the San Francisco Peninsula, and have established to my own satisfaction that the rock in question is an alteration product of serpentine, and that the cases where it appeared to be interbedded must be cases of intrusive sills. It is thus a chemical rock, but due to alteration, and I think the term "Sinter" therefore a misnomer and will not myself use it.

This rock, then, is the final or end product of an interesting chemical transformation in connection with serpentine. It possesses the composition and properties that would be predicted for it apart from any evidence. Remnants of serpentine have been found in this rock, and all stages in the transformation observed.

THE GLAUCOPHANE SCHISTS

The glaucophane schists of the Oak Hill area and vicinity occur as distinct outcrops on the southern and eastern portion of the hills, in general near the periphery of the serpentine. They present nearly as many facies as there are occurrences. It is difficult to observe contact phenomena, but in one instance at least it appears that the glaucophane schist is completely surrounded by serpentine; two other outcrops are closely associated with, if not actually in contact with, jasper; while still in another, glaucophane schist is in the immediate vicinity of sandstone and appears to grade into it.

The glaucophane schists of the Oak Hill area may be described under three heads.

1. *The ordinary typical glaucophane schist.*—In this facies the schistosity is eminently developed, and the schist can be readily split into large thin pieces. It is uniformly bluish in color, and contains flakes of mica which are plainly visible to the naked eye.

The microscope shows this rock to be made up essentially of glaucophane, with some mica, lawsonite, and titanite. The glaucophane prisms show the well-established glaucophane orientation. In the glaucophane the $\mathfrak{a}$ ray is pale greenish-yellow; the $\mathfrak{b}$ ray is purplish-violet parallel to the long diagonal of the basal sections; the ray is sky-blue, and the inclination of $\mathfrak{c}$ to C′ is about 8°. The absorption is $\mathfrak{b} < \mathfrak{c} > \mathfrak{a}$. In addition to the prism, clinopinacoidal

faces were observed on many crystals. The cleavage parallel to the prism is perfect with angles of about 124.°

The lawsonite crystals are comparatively fresh and occur in considerable quantity. A good outcrop of this rock is found near the present workings of the San Juan mine.

2. *The garnetiferous schist.*—The chief difference between this and the typical schist is the relatively smaller amount of glaucophane, the development of numerous garnets, and a somewhat less marked schistosity, the rock being more massive. The garnets, which are irregularly distributed throughout the rock, average about one millimeter in diameter, and can often be detected with the unaided eye. The mica flakes, which are also unevenly distributed, are small, but very numerous. It has been mentioned as eclogite by Mr. R. S. Holway.[1]

The microscope reveals the presence of much garnet and chlorite, some lawsonite, actinolite, glaucophane, and usually also white mica. The garnets usually appear in well-defined crystals, showing high index and high relief. The individuals are nearly always strongly fractured and the cracks filled with green chlorite. In ordinary light the garnets are light reddish-brown in color. The lawsonite is scarce in this rock, appearing as small weathered patches. The green chlorite occurs in abundance in rough, irregularly shaped patches. The glaucophane is not abundant; it occurs as small blue prismatic crystals with properties as described in the typical schist. The mica, like a garnet, is unevenly distributed through the rock. It is of a slightly brownish tint and is probably paragonite.

3. *The acid or quartz-bearing schist.*—The most highly acid exposure of this type of schist was found in close proximity to highly altered banded jaspers in which the typical features, including the banded structure, had disappeared, and the rock was identified only by the presence of radiolaria as shown by the microscope.

The schist is massive and made up almost entirely of silica in indistinct bands of variable thickness, with a little mica on the surfaces. The microscope, however, shows in the slide here and there a deep blue prism of glaucophane imbedded in the silica, and innumerable minute pink dodecahedral garnets.

[1] "Eclogites in California," *Journal of Geology*, Vol. XII, No. 4, (1904), p. 354.

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This rock, then, is the final or end product of an interesting chemical transformation in connection with serpentine. It possesses the composition and properties that would be predicted for it apart from any evidence. Remnants of serpentine have been found in this rock, and all stages in the transformation observed.

THE GLAUCOPHANE SCHISTS

The glaucophane schists of the Oak Hill area and vicinity occur as distinct outcrops on the southern and eastern portion of the hills, in general near the periphery of the serpentine. They present nearly as many facies as there are occurrences. It is difficult to observe contact phenomena, but in one instance at least it appears that the glaucophane schist is completely surrounded by serpentine; two other outcrops are closely associated with, if not actually in contact with, jasper; while still in another, glaucophane schist is in the immediate vicinity of sandstone and appears to grade into it.

The glaucophane schists of the Oak Hill area may be described under three heads.

1. *The ordinary typical glaucophane schist.*—In this facies the schistosity is eminently developed, and the schist can be readily split into large thin pieces. It is uniformly bluish in color, and contains flakes of mica which are plainly visible to the naked eye.

The microscope shows this rock to be made up essentially of glaucophane, with some mica, lawsonite, and titanite. The glaucophane prisms show the well-established glaucophane orientation. In the glaucophane the $\mathfrak{a}$ ray is pale greenish-yellow; the $\mathfrak{b}$ ray is purplish-violet parallel to the long diagonal of the basal sections; the ray is sky-blue, and the inclination of $\mathfrak{c}$ to C′ is about 8°. The absorption is $\mathfrak{b} < \mathfrak{c} > \mathfrak{a}$. In addition to the prism, clinopinacoidal

faces were observed on many crystals. The cleavage parallel to the prism is perfect with angles of about 124.°

The lawsonite crystals are comparatively fresh and occur in considerable quantity. A good outcrop of this rock is found near the present workings of the San Juan mine.

2. *The garnetiferous schist.*—The chief difference between this and the typical schist is the relatively smaller amount of glaucophane, the development of numerous garnets, and a somewhat less marked schistosity, the rock being more massive. The garnets, which are irregularly distributed throughout the rock, average about one millimeter in diameter, and can often be detected with the unaided eye. The mica flakes, which are also unevenly distributed, are small, but very numerous. It has been mentioned as eclogite by Mr. R. S. Holway.[1]

The microscope reveals the presence of much garnet and chlorite, some lawsonite, actinolite, glaucophane, and usually also white mica. The garnets usually appear in well-defined crystals, showing high index and high relief. The individuals are nearly always strongly fractured and the cracks filled with green chlorite. In ordinary light the garnets are light reddish-brown in color. The lawsonite is scarce in this rock, appearing as small weathered patches. The green chlorite occurs in abundance in rough, irregularly shaped patches. The glaucophane is not abundant; it occurs as small blue prismatic crystals with properties as described in the typical schist. The mica, like a garnet, is unevenly distributed through the rock. It is of a slightly brownish tint and is probably paragonite.

3. *The acid or quartz-bearing schist.*—The most highly acid exposure of this type of schist was found in close proximity to highly altered banded jaspers in which the typical features, including the banded structure, had disappeared, and the rock was identified only by the presence of radiolaria as shown by the microscope.

The schist is massive and made up almost entirely of silica in indistinct bands of variable thickness, with a little mica on the surfaces. The microscope, however, shows in the slide here and there a deep blue prism of glaucophane imbedded in the silica, and innumerable minute pink dodecahedral garnets.

[1] "Eclogites in California," *Journal of Geology*, Vol. XII, No. 4. (1904), p. 354.

In other instances the rock appears to be a mica schist, with free quartz intercolated irregularly between the planes of schistosity. The bands are crumpled, and the crystals of glaucophane are broken, distorted, and frequently healed with quartz.

Suggestions as to origin.—The close association of the glaucophanes with the jaspers and sandstones would suggest a genetic relationship. According to F. L. Ransome,[1] the glaucophane schists of Angel Island, San Francisco Bay, are the result of the metamorphism of the radiolarian cherts as well as the feldspathic sandstones. The schist there consists of quartz, albite, glaucophane, biotite, etc. Some of the Oak Hill rocks are very similar to those in composition. This close association of the glaucophane schists and jaspers has been commonly observed in the Coast Ranges of California.

Some of the Oak Hill glaucophane schist is rich in argillaceous matter. Near the border of this schist fairly large flakes of a light brown mica have been developed, while nearer the center of the mass little or no mica appears.

Although no positive general statement can be made with reference to the origin of the glaucophane schist, nevertheless it is certain that at least in some cases they are the products of the metamorphism of sediments. This is undoubtedly true of the more siliceous facies, while the more basic facies may have resulted from the alteration of tuffs of ingneous rocks. Ransome ascribed their origin to contact metamorphism, while Nutter and Barber[2] thought that dynamic metamorphism alone could account for the origin of the greater schist masses of the Coast Ranges. It would appear that further investigation along the line of mineralizing effects of solutions in metamorphic zones is necessary to explain the genesis of glaucophane and associated minerals.

MAGMATIC DIFFERENTIATION

In the foregoing description of the gabbros, pyroxenites, and serpentines with their products, it has been pointed out that, while all the rock types are very distinctly shown, nevertheless the transitions are

[1] *Bulletin of the Department of Geology of the University of California*, 1894, pp. 193–240.

[2] *Journal of Geology*, Vol. X, No. 7 (1902), p. 742.

so evident that it has been found artificial to make separate classes. The field indications show conclusively that the pyroxenite grades into the typical gabbro on the one hand, and into the olivine-pyroxenite on the other. Further, this olivine-pyroxenite, which in one phase is practically a diallagite, in other phases goes by insensible gradations into peridotite-serpentine; that is, the phase of the pyroxenite, richest in olivine (peridotite) has become serpentinized and gives us peridotite-serpentine and serpentine.

This serpentine, it has been suggested, gives up its iron, yielding veins of magnesium-silicate, which in turn liberates silica, takes up carbon-dioxide, forming magnesium-carbonate. Thus we find over the area the free oxides of iron veins and patches of magnesium-silicate, and, where conditions favor the taking-up of carbon-dioxide, magnesium-carbonate. When the carbonates, silicates, free silica, and iron-oxides are all mixed in one complex rock, we get a product that has been described under the name "silica carbonate sinter."

The hypersthene gabbro in the field has not been observed in direct connection with the other rocks of the gabbro-pyroxenite-serpentine series; it, however, shows no evidence of intrusion. It is in very close proximity to the typical gabbro, and is found nowhere else over the area. Its mineralogical variation, moreover, would lead to the conclusion that it is but a phase of the ordinary typical gabbro.

Olivine, it has been noted, is common to all this rock series, increasing in freshness from the serpentine to the hypersthene-gabbro. These rocks also have a banded structure in common. The mineral diallage is also common to all the rocks of the series. Its ratio to olivine accounts for the variations from diallagite, olivine-pyroxenite, peridotite-serpentine to serpentine. In acidity we have an increase from 37.71 per cent. of silica in the serpentine to 48.11 per cent. in the gabbro.

The authors, in conclusion, wish to express their thanks to Dr. J. P. Smith, for his constant aid and advice; to Dr. J. C. Branner, for the chemical analyses secured from the United States Geological Survey. Mr. F. H. Tibbetts, a former student of Mr. Carey's, aided materially in the construction of the topographic map.

SOME OBSERVATIONS ON THE MOVEMENTS OF UNDERGROUND WATER IN CONFINED BASINS

A. R. SCHULTZ
U. S. Geological Survey, Washington, D. C

In 1905, while pursuing my geologic studies at the University of Chicago, I had an opportunity of doing some experimental work on the motion of underground waters in confined basins. Although the time and equipment for experimentation were limited, an attempt was made to ascertain as nearly as possible from a given set of conditions what effect distance from the outcrop area has upon the flow or yield of a well; how an increase in head modifies the flow or yield of a well; with what regularity friction increases as the distance from the outcrop area is increased; and what effect confined air between the water table and a surface layer of water has upon the water level in a well. It is not supposed that any rigid deductions can be made from a set of single experiments. It is necessary, before making such deductions, that several kinds of material be tested under somewhat different conditions to see whether or not they agree in the essential points. For this reason no deductions will be made, but the facts observed in the experiment are recorded and may be compared with known conditions in other artesian basins.

To determine the above factors a miniature artesian basin was arranged in the basement of Walker Museum and the experiment begun. The basin consisted of an eight-inch steam pipe 40 feet long, and closed at one end. The pipe was placed in position as shown in Fig. 1, and then filled with clean, dry sand, packed as firmly as possible by tamping the sand with a rod as the pipe was being filled. Five $\frac{3}{8}$-inch wells were drilled at points *A*, *B*, *C*, *D*, and *E*. In each of these wells was inserted a casing $\frac{1}{4}$-inch in diameter and 9 inches long. The lower 8 inches, which extended down into the sand consisted of a cylindrical wire screen, surrounded on the outside by one thickness of cheese-cloth to prevent the finer sand grains from being washed into the well and filling it. The upper portion of the casing, which projected through the steam pipe and furnished the ground connection of the well, was a cylindrical brass tube $\frac{1}{4}$-inch in diam-

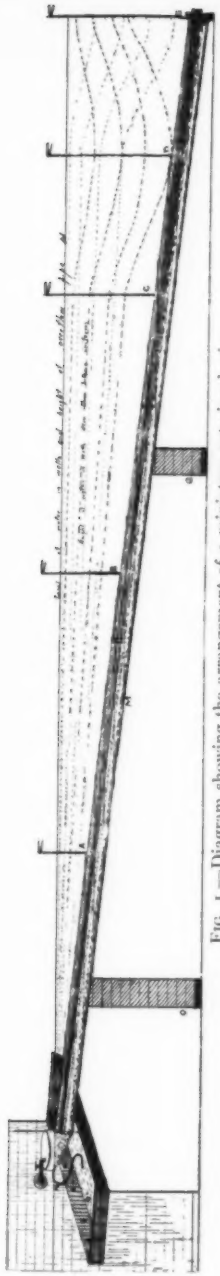

FIG. 1.—Diagram showing the arrangement of a miniature artesian basin.

eter and one inch in length, to which the lower 8 inches were soldered. When the casing was in place the remaining space in the well outside the casing was filled with sand and the space between the brass well casing and the iron pipe sealed, making a water-tight contact and leaving no passage for the water within the iron pipe except through one of the five wells. Above ground or outside the iron pipe each well casing was connected with $\frac{1}{4}$-inch rubber tubing, long enough to extend higher than the intake of the iron pipe. To facilitate reading the height to which the water in the well rose and to make it easier to collect the water flowing from the wells, the end of each tubing was provided with a foot of $\frac{1}{4}$-inch glass tubing bent at right angles as shown in diagram.

With the apparatus in position as above shown, the water was turned on and the sand within the pipe allowed to absorb as much water as possible—the surplus escaping through the overflow pipe *N*. In order to ascertain with what velocity the water flowed through the pipe the tubing at well *E* was disconnected at the brass casing and an indicator to report the final arrival of water inserted into well *E*. The time from the turning on of the water until it arrived at *E* was found to be 25 hours and 40 minutes. The velocity was therefore 1.56 feet per hour or .31 inches per minute. The average diameter of the sand grains as determined by measurement of 1,000 grains was .43 mm and the porosity of the sand 39.2 per cent.

The tubing at well *E* was replaced and in a short time the water in each well stood

at the same level as the overflow pipe. The basin was saturated, the water ponded, and no more water entered the sand, but all escaped through the overflow pipe.

It was believed that the water flowing through the pipe would readjust the sand particles and succeed in packing them into smaller space than was done on filling the pipe with sand. To accomplish this the well tubing at each well was placed in a receptacle on the floor of the basement, and the water allowed to flow freely from the wells. At short intervals the pipe was revolved in order to assist in packing the sand. This process was continued for two days, and as the sand settled in the pipe a new supply was added at the intake. When the pipe was entirely filled and no further settling took place the wells were put back in position shown in Fig. 1, and the water in the wells soon stood at the level of the overflow pipe. A constant head was maintained at the intake by allowing enough water to flow so that a small stream or the surplus water escaped through the overflow pipe.

Tests were now made to ascertain the yield per well at different heads. The water at one of the wells was allowed to flow at a given head until the flow became constant. The head was then increased and maintained until the flow again became constant, and so on until each well in turn was tested.

The test at each well was begun only after the water in all the wells stood on a level with the overflow pipe and they were, therefore, independent of each other. The flow or yield per well at a given head was determined by collecting the discharge per minute, as timed by a stop watch, and weighing the water thus collected. The results obtained in this test are set forth in the tables appearing on the following pages.

Another series of tests were made similar to those in Table I. This time, however, the flows at the various wells were not given time to become constant. Each measurement at the five wells was taken only after the water in all the wells stood on a level with the overflow pipe. After each measurement time was allowed for the water to regain its normal condition. The figures therefore in this table indicate the flow during the first minute after the well is allowed to flow at a certain head.

TABLE I

SHOWING DECREASE IN FLOW DURING THE FIRST STAGES OF PRODUCTIVE WELL AND THE INCREASED YIELD DUE TO INCREASED PRESSURE

WELL	TIME INTERVAL AT WHICH FLOW WAS TESTED	FLOW IN GRAMS PER MINUTE			
		1 Ft. Head	2 Ft. Head	3 Ft. Head	4 Ft. Head
	Minutes				
	0	245			
	10	220			
	20	195			
	30	165			
	40	142			
	50	120			
A	60	110			
	70	100			
	80	91			
	90	82			
	100	84			
	110	82			
	120	82			
	0	216	365		
	10		330		
	20	198	305		
	30	180	285		
	40	166	256		
	50	150	225		
	60	135	205		
B	70	115	182		
	80	99	166		
	90	89	161		
	100	88	159		
	110	89	159		
	120	89	159		
	130	89	159		
	Increase in flow		70 g or 79%		
	0	215	325	370	
	10	199	308	346	
	20	190	291	324	
	30	172	271	310	
	40	160	252	289	
	50	151	230	278	
	60	145	215	265	
C	70	136	198	252	
	80	116	184	245	
	90	106	170	237	
	100	99	164	236	
	110	91	162	237	
	120	91	162	235	
	130	91	165	236	
	Increase in flow		74 g or 81%	71 g or 78%	

TABLE I—*Continued*

Wells	Time Interval at Which Flow Was Tested	Flow in Grams per Minute			
		1 Ft. Head	2 Ft. Head	3 Ft. Head	4 Ft. Head
	0	225	351	390	420
	10	195	332		
	20	180	310	345	
	30	160	290	330	370
	40	150	270	315	356
	50	138	240	289	340
	60	123	220	268	328
D	70	110	205	252	310
	80	100	190	228	208
	90	92	172	222	290
	100	91	129	219	286
	110	90	154	220	284
	120	89	154	220	284
	130	90	154	220	284
	Increase in flow		64 g or 71%	66 g or 73%	64 g or 71%
	0	166	179	198	215
	10	140	155	172	203
	20		122	160	192
	30		105	151	180
	40	64	96	140	171
	50	56	95	128	160
	60	50	83	120	156
E	70	48	83	115	152
	80	48.2	83	115	150
	90	48.3	83		150.2
	100	48.2		115	150.4
	110	48.2			
	120		83	115	150
	130	48	83	115	150
	Increase in flow		35 g or 73%	32 g or 67%	35 g or 73%

On examining the above two tables it is evident that the flow at each of the wells for a given head is about the same. Well *D* at a given head furnished as much water as well *A*, *B*, or *C*, although its distance from the outcrop is much greater. Well *E* is the only exception. The decrease in yield here is due, no doubt, to the nearness of the well to the end of the pipe which greatly reduces the area supplying the well.

The flow or yield per well does not increase at the same rate as the pressure but lags somewhat behind. As determined from the various measurements recorded in Tables I and II, the flow or yield per well approximates 73 per cent. of the increase in pressure or head. In other words, doubling the head increases the flow by about 73 per cent. In a test made by Professor Turneaure for the Madison waterworks

TABLE II

SHOWING THE INCREASE IN FLOW DUE TO INCREASE IN HEAD

WELLS	FLOW IN GRAMS PER MINUTE			
	1 Ft. Head	2 Ft. Head	3 Ft. Head	4 Ft. Head
A	245			
	Increase in flow			
B	216	388		
	Increase in flow	172 or 71 %		
C	215	383	540	
	Increase in flow	168 or 78%	157 or 73%	
D	225	390	555	710
	Increase in flow	165 or 73%	165 or 73%	155 or 72%
E	166	279	397	516
	Increase in flow	113 or 68%	118 or 71%	119 or 71%

Commissioners in 1903 the capacity of the Main Street well (No. 10) at Madison, Wis. (see Fig. 2), was found to be 599,000 gallons per day when the water stood 18 feet below the surface. On lowering the water to a depth of 72 feet below the surface the yield was increased to 1,500,000 gallons per day, the increase in flow being only 63 per cent. of the increase in head.

Table I shows that the flow at any well was at a maximum when the well was first tapped or allowed to flow. The flow then gradually decreased and finally became constant. During this decrease in flow the water in the remaining wells gradually lowered and readjusted itself. The final position of the water in the wells after the flow became uniform in wells *D* and *E* is shown by the dotted lines in Fig. 1. The greater flow during the first stages is probably due to the fact that the water immediately adjacent to the well finds ready entrance into the well with comparatively little friction. As the water farther from the well is drawn upon, the friction becomes greater and greater as the distance the water moves through the sand particles increases, and the yield consequently less and less. Finally the well adjusts itself to its new conditions of head and friction, and the yield becomes fairly uniform.

The point of interest here is that the wells farthest from the intake yield as strong a flow as those one-third or one-fourth the distance

from the intake. This suggests that the friction which is the cause of cutting down the flow is restricted largely to the vicinity of the well where the water is moving with the greatest velocity. Much the same conditions probably exist in the Wisconsin artesian basin, where in the vicinity of Green Bay, Milwaukee, Wis., and Chicago, Ill., the head has been reduced approximately 100 feet since the first flowing wells were put down, while many of the wells between these locations and the intake area have practically the same head as when first drilled. Recent wells drilled between the above-named localities and the outcrop region show that there is no corresponding decrease in head to that noted in the vicinity of Green Bay, Milwaukee, and Chicago. It follows, therefore, that through the major distance of the sandstone the friction of the water is almost zero, or the pressure at the wells would not so nearly equal the pressure due to head.

When wells are allowed to flow or are heavily pumped, the pressure in the vicinity of the well rapidly drops, while at a distance of several thousand feet the pressure is often as great while the well is flowing or heavily pumped as it was before the flow or pumping began.

That the influence of a well extends to a very considerable distance is shown in a general way by the following tests made in Madison, Wis., by the Waterworks Department in 1903 (for location of wells see Fig. 2):

	No. Gallons per Day
1. One well at the pumping station yields	500,000
2. Four wells at the pumping station yield	1,000,000
3. Four wells at the pumping station, and four wells scattered along a line 3,000 feet long yield	1,750,000
4. Four wells at pumping station and one remote well yield	1,300,000
5. Main Street pump (Well No. 10), not running the Blount Street well (No. 8), yields	984,000
While the remainder of the wells yield	2,240,000
6. Main Street and Blount Street pumps both running, the two wells yield	1,944,000
(or nearly twice the yield of the Blount Street well in Par. 5) while the remainder of the wells yield	1,300,000

When the Madison wells were first drilled the water overflowed 4.5 feet above Lake Mendota, or 854.5 feet above tide. At present propeller pumps are installed at the Main Street well (No. 10) and

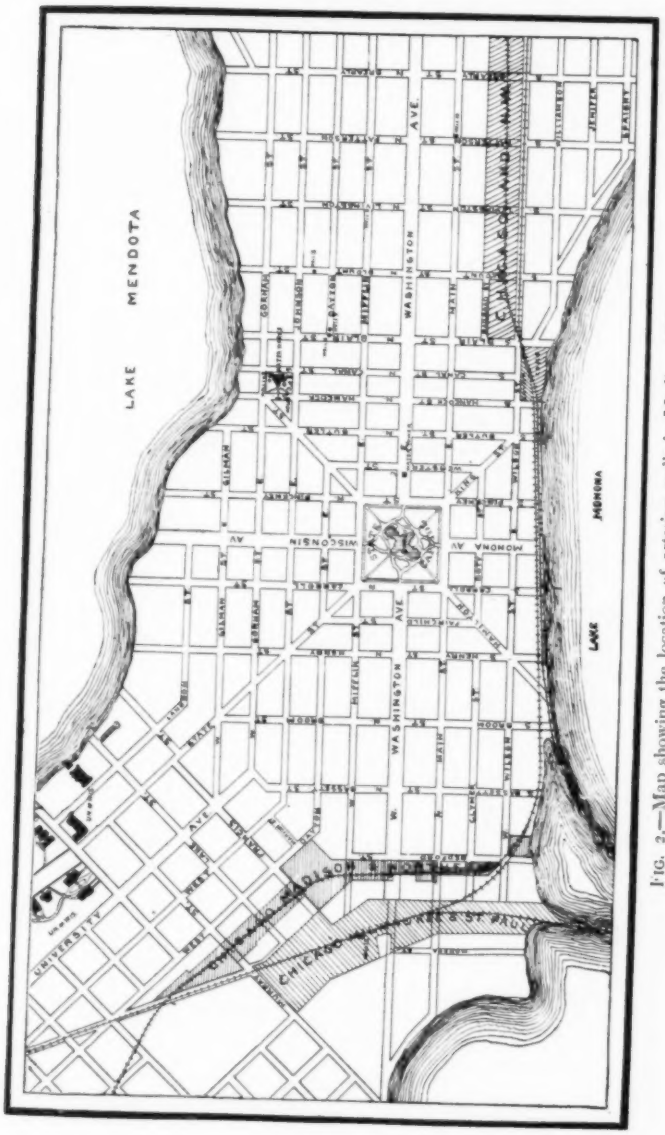

FIG. 2.—Map showing the location of artesian wells in Madison, Wis.

DESCRIPTION OF FIG. 2

	Diameter	Depth	Owner
Well 1	8 inches	751 feet	City of Madison (Waterworks)
" 2	8 "	226 "	
" 3	6 "	751 "	
" 4	6 "	751 "	
" 5	8 "	751 "	
" 6	8 "	751 "	
" 7	8 "	226 "	
" 8	8 "	751 "	
" 9	10 "	821 "	
" 10	10 "	736 "	
" 11		1015 "	State of Wisconsin
" 12		795 "	Chicago, Milwaukee & St. Paul Ry. Co.

Blount Street well (No. 8). All other wells (see Fig. 2) are connected with the suction of the pumps at the pumping station. The Main Street well is scarcely affected, while the pumps at the pumping station, with a vacuum of about 18 inches, are drawing water. The nearest well of the group, the Livingston Street well or No. 9, is only 1,000 feet from the Main Street well No. 10. When the Blount Street propeller pump is working and the water in the well lowered 72 feet, the water in the Main Street well, 2,000 feet from the Blount Street well, recedes about 14 feet, and then remains stationary. Tests of well No. 12 at the C. M. & St. Paul roundhouse, a mile distant, fail to show any effect of the pumping at the city well, even while the water in the wells No. 10 and No. 8 was 72 feet below the surface and the total capacity of all the wells was 3,200,000 gallons per day.

As clearly indicated by the experiment and by the above tests the drop in the water level in the vicinity of a well is not due so much to the friction through the major course of the water where the movement is slow, but is chiefly due to the friction in the vicinity of the well, where the water is moving on its way to the well and on through the casing itself until it reaches the surface. Back a short distance from the well the water oozes slowly from the small openings and maintains the same head as before the well was pumped or allowed to flow.

Several tests were made to see what effect confined air between the water table and the gathering ground would have upon the water level in the wells. During this experiment well *A* was sealed so that no air could escape through it. The water in the pipe stood 1 foot 2 inches below the escape pipe, when water was turned on and the

sand at the outcrop allowed to absorb as much of the water as possible. Ten minutes after the water was turned on the water in the wells stood 1 foot below the escape pipe, indicating a rise of the water in the wells of two inches. Occasionally air bubbles would escape at the intake, causing a slight fluctuation of the water in the wells. On opening well *A* and allowing the air to escape, the pressure of which was strong enough to force paper away from the mouth of the well, the water in the wells *B*, *C*, *D*, and *E* dropped back to its original level, 1 foot 2 inches below the escape pipe, thereby showing that none of the water recently added to confine the air had reached the water table.

The water in the pipe was now lowered to 2 feet 11 inches below the overflow pipe, the other conditions being the same as in the first test. Ten minutes after water was turned on, the head at wells *B*, *C*, *D*, and *E* was 2 feet 9 inches below the overflow pipe. The pressure on the confined air increases as the sand absorbs more water, and when the pressure becomes great enough some of the air rises through the sand and water and escapes at the outcrop. The instant a large bubble of air escapes there is a very slight drop in the water level in the wells.

Thirty minutes after the water was turned on the water in the wells *B*, *C*, *D*, and *E*, stood 2 feet 8.5 inches below the escape pipe, indicating a rise of 2.5 inches. On opening well *A* and allowing the confined air to escape the water in wells *B*, *C*, *D*, and *E* dropped back to 2 feet 11 inches, thereby indicating that none of the recently added water had been added to the water table. The rise of the water in the wells in both of these cases was therefore due to the confined air between the water table and the newly added water layer near the intake; a condition which to a greater or less degree prevails during every rain storm, when the water absorbed by the surface shuts in more or less air between the surface layer of water and the water table. The effect of this additional pressure upon the yield at springs or wells is evident.

In a region of flowing wells like that of southern Wisconsin and northern Illinois where the porous beds are saturated with water and the water more or less ponded, the yield at any given well depends largely upon the conditions of the beds in the immediate vicinity of

the well, and not so much upon the transmitting power of the porous beds between the well and the outcrop area. As indicated by the tests in this experiment, as well as in the Madison test above cited, the disturbance caused by the water, escaping at a well, soon dies out as the distance from the well becomes greater and greater. Seldom in the Wisconsin district does the disturbance extend more than a mile back from the well.

The movement of the water in these ponded basins is very slow. In the Wisconsin area where the annual precipitation approximates 30 inches, probably not more than one fifth or 20 per cent. of this amount is added to the ponded sea. On the other hand it may be considerably less than 20 per cent., for no accurate determinations are at hand which give the exact amount of run-off in the Wisconsin region. To the amount of immediate run-off must also be added the amount that returns to the surface by evaporation, by vegetation, springs, and shallow wells.

Assuming, however, that 20 per cent. is a fair estimate of the amount of precipitation that is added to the ponded sea and that $16\frac{2}{3}$[1] is the average pore space of the Potsdam sandstone, we can compute the rate of flow.

In order that 20 per cent. of the precipitation may be added to the ponded sea without raising the water level, the increment of the previous year must have moved vertically downward 3.6 feet.

The dip of the Potsdam sandstone as indicated by wells between Madison, Wis., and Chicago, Ill., is about 12 feet per mile. It follows, therefore, that the lateral movement of the water amounts to 1760 feet per year or one-third of a mile. As much of the Potsdam sandstone gathering ground lies 200 miles northwest of Chicago, it is evident that the water collected by the catchment area will require in the neighborhood of 600 years before it reaches Chicago. If the average pore space of the sandstone is larger than $16\frac{2}{3}$, the downward movement of the water as above computed would be less, and if the pore space was smaller, the downward movement would have to be greater, in order to hold the 20 per cent. of the precipitation. It also follows

[1] C. R. Van Hise, "A Treatise on Metamorphism." Monograph 47. *U. S. Geological Survey*, pp. 585–89.

that the coarser the sandstone and the more porous, the greater will be the amount of water available at any given well.

That the pore space in many cases is larger is evident. For example in the Prairie du Chien well, drilled in 1903, for the Sanitarium, a coarse bed of sandstone was entered at 720 feet below the surface and continued down to 805 feet, passing through 85 feet of coarse porous sandstone. The pore space of this sand as determined by the writer from several samples taken from the well was found to be 30. The size of the sand grains were very large, making this 85 feet horizon by far the strongest flow of water struck in the well. The average size of grain as determined by measuring 1,000 representative grains was .92^{mm}.

The maximum and minimum dimensions of eleven of the larger grains are tabulated below and give a fair idea of the coarseness of the sand grains.

TABLE III

DIMENSIONS OF SAND GRAINS IN POTSDAM SANDSTONE, PRAIRIE DU CHIEN, WISCONSIN

	Minimum Dimension	Maximum Dimension	Average
1.....	2.43^{mm}	5.35^{mm}	3.98^{mm}
2.....	3.32	3.47	2.39
3.....	2.30	3.26	2.78
4.....	2.00	3.30	2.60
5.....	1.29	3.38	2.34
6.....	1.80	2.93	2.36
7.....	1.70	3.08	2.39
8.....	1.51	3.22	2.37
9.....	1.50	2.84	2.17
10.....	1.55	2.70	2.12
11.....	1.60	2.56	2.08
			2.50

Editorial

The spirit of seismological research has more than once been awakened by a great disaster. The Mino-Owari earthquake in Japan, which occurred in October 1891, and was the most disastrous in more than thirty-five years within that seismically classic province, gave birth to the famous Earthquake Investigation Committee, known as the E. I. C. Its objects were announced to be: (1) "*to investigate whether there are any means of predicting earthquakes;*" and (2) to see "*what can be done to reduce the disastrous effects of earthquakes to a minimum.*" After more than fifteen years of research, to which the ablest minds of Japan have contributed, it is necessary to admit that it is only the last-mentioned endeavor which has been crowned with success.

In 1896 the Committee on Seismological Investigations of the British Association for the Advancement of Science, whose founder and energetic secretary is Professor John Milne, made its first report replacing an earlier standing committee which reported upon the volcanic and earthquake phenomena of Japan. In the following year the well-known *Erdbebenkommission* of the Vienna Academy of Sciences was founded. The value to the world of science of the three committees above mentioned it would be difficult to estimate.

The disastrous California earthquake of April 18, 1906, has been signalized by the formation of a Committee on Seismology of the American Association for the Advancement of Science; which committee, like its British cousin, is composed of fifteen members. The gentlemen selected, who represent all sections of the country, and the more important institutions likely to be engaged in seismological research, are as follows: L. A. Bauer, Carnegie Institution; W. W. Campbell, Lick Observatory; C. E. Dutton, U. S. Army, Washington, D. C.; G. K. Gilbert, U. S. Geological Survey; J. F. Hayford, U. S. Coast and Geodetic Survey; W. H. Hobbs, University of Michigan; L. M. Hoskins, Stanford University; T. A. Jaggar, Massachusetts Institute of Technology; Otto Klotz, Ottawa Observatory;

A. C. Lawson, University of California; C. F. Martin, U. S. Weather Bureau; W J McGee, St. Louis Public Museum; H. F. Reid, Johns Hopkins University; C. J. Rockwood, Jr., Princeton University; and R. S. Tarr, Cornell University. In the preliminary organization of the committee Dr. G. K. Gilbert was chosen chairman and Dr. W. H. Hobbs, secretary.

Some of the objects in view in forming the committee on seismology in America are as follows:

1. To be available for, and to initiate counsel in connection with, legislation which provides for investigation of earthquakes or the means for mitigating their dangers.

2. To bring into harmony all American and Canadian institutions doing seismological work, and to guard against unnecessary duplication of studies.

3. To organize, if thought best, a correlated system of earthquake stations, which should include the outlying possessions and protectorates.

4. To advise regarding the best type or types of seismometers for the correlated stations.

5. To disseminate information regarding construction suited to earthquake districts.

6. To collect data regarding the light as well as the heavy shocks, and to put the results upon record.

7. To start investigations upon large problems of seismology.

8. To advise with some weight of authority when catastrophic earthquakes have wrought national calamity.

An additional object of the committee's conferences has been suggested by the latest disaster in Jamaica. Press notices, presumably correct, call attention to marked changes of soundings within the harbor of Kingston as a result of the earthquake; and the interruptions of the Bermuda and Panama cables probably register larger movements along the scarps bordering the great deeps. The region as a whole (and the harbor of Kingston in particular) is one within which particularly accurate soundings have been made. A resurvey as early as is practicable will probably yield valuable data regarding the nature of under-sea changes at the time of earthquakes. There is probably today no portion of the field of seismological research so little exploited, and yet so full of promise, as the study of data already in the possession of telegraphic cable companies. The little already accomplished by Milne has demonstrated both the value of these data

and the reluctance with which the cable companies consent to part with them. The committee should see whether, either alone or in co-operation with the British committee, something may not be accomplished in securing access to these valuable data. If the companies could be made to see that studies by the committee are likely to serve them in suggesting better methods of meeting their special difficulties, much might be gained.

Almost at the same time that the American Committee on Seismology was founded there was organized upon the Pacific coast the Seismological Society of America. Though the name is as broad as the continent, the composition of the Board of Directors and the Scientific Committee indicates that the field of the society's endeavors is to be the Pacific states. The president of the society is George Davidson, and the secretary George D. Lauderbach. The chairman of the Scientific Committee is Professor Andrew C. Lawson, who is also first vice-president of the Board of Directors. The other members of the Scientific Committee are J. C. Branner, G. K. Gilbert, C. Derleth, Jr., J. U. Le Conte, A. S. McAide, and H. F. Reid. Membership in the society is fixed at $2 per year for ordinary membership and $25 for life membership. It is announced that a regular publication is one of the objects of the society. An American journal of seismology would do much to develop the latent interest in the subject, and it is to be hoped that one will soon be launched.

There is another movement, less in evidence as yet, but hardly less certain to arrive. Several American universities following the example of Johns Hopkins, are now making plans for the equipment of an earthquake station, and close upon these installations is sure to follow a new emphasis placed upon seismology as a part of a geologist's training. The chair in seismology founded in the University of Tokyo in 1886, and occupied successively by the distinguished seismologists Sekiya and Omori, is today unique in the world; and, with the exception of an unsuccessful course in seismology given years ago at the Sorbonne, the branch has not been dignified as yet by separate treatment in the university curriculum. A beginning has just been made at the University of Michigan, where in the winter semester of 1906–7 a lecture course upon seismic geology has been given two hours each week. W. H. H.

Under the civil polity of the United States, certain functions which relate to the welfare of the whole nation are assigned to the national government, while other functions of more circumscribed bearings are reserved to the states. The principles which underlie this polity are as applicable to the scientific functions of the government as to any other. Those inquiries which bear upon the common welfare, irrespective of state limits, fall within the sphere of the national investigative organizations; those which relate to local interests belong to the province of the state scientific organizations, or to those instituted by municipal or other sub-state governments. It is obviously easier to state this basis of division than to apply it; for few scientific inquiries are so local as not to benefit the whole nation, directly or indirectly, and few are so general that they do not affect the welfare of the people of one state more than those of others.

None the less, if these general principles are clearly apprehended and kept steadily in mind, a working system in reasonable accord with them can be established and maintained in the scientific field, as it has been for more than a century in the political. It is clear that those problems which are embodied in the phenomena of more than one state in such a way that the investigations necessary for their solution must be pursued in neglect of state lines, fall within the functions of the national organization; while those which lie wholly within state limits, and do not bear trenchantly on any fundamental or general problem, as clearly fall within the functions reserved to the states respectively. Into the one or the other of these two great classes fall no small part of the geological problems of the domain belonging jointly to the nation and the states, and these may be easily distinguished in practice. Until we change our system of government, the national survey should not undertake the latter class of problems, nor the states the former. The intermediate class of problems, not so clearly defined, are to be compassed by co-operation and mutual agreement.

If these considerations are true and just, it is clear that every state has a scientific function to perform; for no state government is true to the interests of its people, in this stage of human evolution, that does not care for the intellectual as well as the political welfare of its

people, and scientific inquiry is fundamental to the intellectual development of every progressive people.

We hold, therefore, that no state is doing its duty to its people, or its part as a factor in our governmental system, which does not maintain a well-organized system of scientific investigation covering the essential physical conditions and the potential resources that relate to the health, prosperity, and happiness of its people. Among these we naturally place a geological survey. A state is shirking its duty and its responsibility, if it leaves all this investigative work to the national government. It is not right for the national government to do it all, as functions are now apportioned. Let every state, therefore, do its part zealously. Let the national government do its part, but only its part. A spirited endeavor by each to fulfil its functions, attended by a generous co-operation when the dividing line between functions is obscure or debatable, will develop and preserve, in the scientific field, that community of action in promoting the higher welfare of our people which is the soul of our civil polity.

T. C. C.

Reviews

Structural and Field Geology. By James Geikie. New York: S. Van Nostrand Co. Pp. xx+435, 56 full-page plates, 142 illustrations in text.

The student whom Mr. Geikie seems to have had most prominently in mind, during the preparation of this work, is the prospective mining engineer. The book is an excellent handbook for those wishing to make some practical use of geology or to study the science from a practical standpoint.

The first five chapters deal with rock-forming minerals and rocks. In chap. vi the modes of preservation of organic remains in rocks are described, and the significance of fossils in geologic studies is briefly pointed out. Chap. vii treats of stratification, and chap. viii of concretionary and secretionary structures. There then follows a full and well-illustrated description, occupying the next four chapters, of the structures common to sedimentary rocks. The mode of occurrence and the structural relationships of eruptive rocks are treated in chaps. xiii and xiv. After the student has a knowledge of the chief materials of the earth, of the aggregation of these materials in the common rock formations, and of the attitudes and relationships of these formations, he is invited to consider the alteration and metamorphism of such materials and formations. Chap. xv is devoted to the consideration of such changes. In chaps. xvi and xvii ore formations are carefully figured and described.

The next three chapters, xviii–xx inclusive, are devoted to geological surveying, and chap. xxi to the preparation of geologic maps and sections. These four chapters include numerous practical suggestions on field equipment, field methods of work, devices for keeping notes on maps, etc.; they are addressed to beginners in field-work, and to them should prove very valuable. Chaps. xxii and xxiii deal with some economic aspects of geological structures. They include such topics as: the search for coal, conditions under which coal occurs, the search for ores, general considerations which should guide the prospector, geological structure and engineering operations, reservoirs, underground water, springs, common artesian wells, and the distribution of disease in relation to geological conditions. Soils and subsoils are the subject-matter for chap. xxiv and the

closing chapter, xxv, is devoted to a study of the relation of surface features to geologic structures.

Throughout the volume Mr. Geikie has limited himself to the more settled doctrines and principles of working geology, and has not attempted to present alternative views or possible objections. He has avoided the presentation of many of the problems now engaging the attention of structural geologists.

The photographic illustrations deserve special mention for their excellence, and among them the photographs of rock specimens are the most remarkable.

W. W. ATWOOD

The Viscous vs. the Granular Theory of Glacial Motion. By OSWIN W. WILLCOX. Long Branch, N. J.: Published by the author, 1906. Pp. 23.

This is less a treatment of the theme implied by the title than a review of a particular statement of one phase of the granular theory.[1] Even as a special criticism it goes wide of the mark, as the author, inadvertently it is to be assumed, substitutes easily demolished propositions of his own for those of the sponsors of the granular theory. As the leading feature of his discussion, Dr. Willcox attributes to the special sponsor he selects the unlimited proposition that "strictly crystalline minerals are incapable of manifesting viscous fluidity," whereas the real proposition is the very special one that "the retention of *its* crystalline structure," by the *ice granule*, during glacial *motion*, is incompatible with a *viscous flowage* of the granule. The "universal principle" thus substituted for the special proposition is attacked by the citation of the peculiar phenomena manifested by certain organic compounds, called, with more or less questionable propriety, "crystalline liquids" and "liquid crystals." These interesting phenomena have been all along known to some of the sponsors of the granular theory, presumably to all, and have awakened the question whether these "liquid crystals" are not short of being *typical liquids* to the extent that they are "crystalline," and short of being *typically "crystalline"* to the extent that they are liquids. The more vital question, however, is whether or not they *retain* their "crystalline" character while undergoing continuous and protracted motion under stress. Had these questions been sharply discussed, with full and critical data, the contribution would have been at least suggestive as to theoretical possibilities of beha-

[1] Chamberlin, *A Contribution to the Theory of Glacial Motion*, University of Chicago Press, 1904.

vior in ice granules, but it would not have touched the real question how they actually behave. Nothing truer can be said of this academic discussion of a universal proposition substituted for a concrete and special one, than is said by the author in another part of his paper, where the aspect of his discussion is reversed: "But the laws of nature, considered apart from their special modes of action, have little interest or value in either theory or practice."

By way of showing how concrete and special the real propositions involved in the granular theory are, they may be put as follows:

I. Glaciers are formed of individual crystalline granules. II. These are controlled by a strong crystalline force. III. They are, however, subject to growth and decadence, resulting in the extinction of some crystals and the enlargement of others, and in changes of relations to one another. IV. The crystals of any part seem to be the enlarged or reduced descendants of those in the part above. V. Collectively they persist throughout the whole glacial movement, and individually they seem to persist through some notable part of it, at least. VI. They participate in the changes of form and the changes of attitude involved in the glacial movement. Now:

1. If the granules are deformed by a viscous movement within themselves, they should show the fact by the recognized characteristics of viscous deformation and flowage.

2. If the granules are deformed by fracture and regelation, they should show the characteristics of this action.

3. If they are deformed by the sliding of the gliding plates of the crystals over one another, they should show this.

4. If they retain their crystalline integrity, save for additions and losses, they should show this.

These are very definite, concrete alternatives, to be settled by studies on the actual phenomena of glaciers, and in no other way. The incompatibility of the last with the first is the specific incompatibility urged, not the universal incompatibility of all kinds of crystallinity with all kinds of viscosity.

No evidence of the first is known to the reviewer; the second is manifested locally; the third seems to have an important place under special conditions of stress; while the fourth seems to be abundantly evidenced by the characters and attitudes of the granules. Dr. Willcox is a young chemist, with a geological penchant, whose lack of personal familiarity with the intimate structure of glaciers does not permit him to discuss these propositions on the only basis that is entitled to weigh—that of observation.

In the latter part of the paper he questions the adequacy of the energy available for glacial movement. Instead, however, of following carefully the postulates of the granular theory, he substitutes postulates of his own which any advocate of the theory would repudiate. For example, instead of trying to estimate the value of the gravitative pressure and the insolation, direct and indirect, which are the sources of the energy of movement assigned by the sponsors of the theory, he discusses the value of the *impact* of the moving granules, and seems seriously to regard the energy represented by the velocity of the granules as the total energy available!

Preliminary to an effort to show that there are narrow limits to the possibilities of glacial advance under the granular theory, the author says: "According to this theory, as it is stated by its sponsors, the elongation of a glacier is due primarily to the relief from compression afforded by the intergranular spaces;" and on this basis he proceeds to discuss the limits of the compression of the granules and the insufficiency of the intergranular spaces. His special sponsor for the theory, however, says, after detailed exposition: "These considerations lead to the view that movement takes place by the minute individual movements of the grains upon one another." It is difficult to find an excuse or palliation for such substitutions of propositions, indefensible on their face, for the propositions actually advanced by the sponsors of the granular theory. If a subject so infelicitous for academic treatment as the minute dynamics of glaciers is chosen at all, it is natural to expect it to be treated with academic fidelity.

T. C. C.